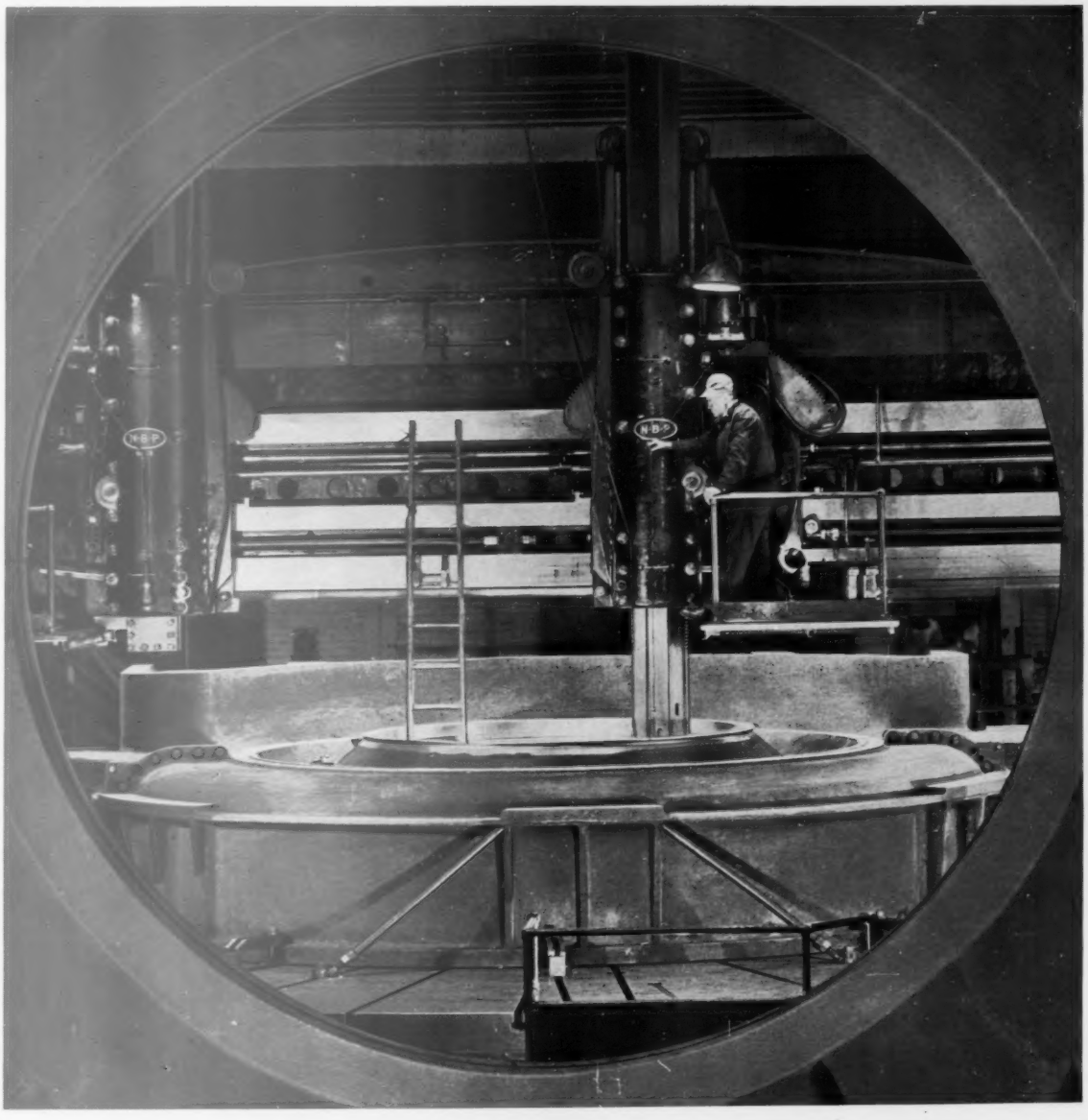
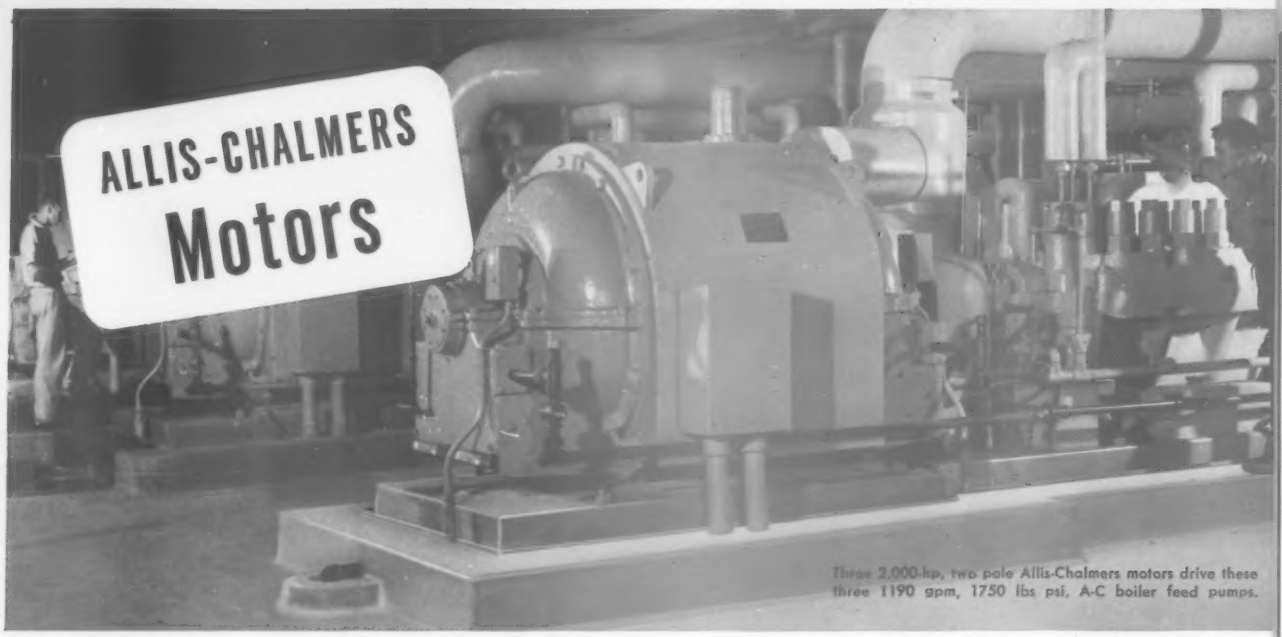
ALLIS-CHALMERS Electrical REVIEW



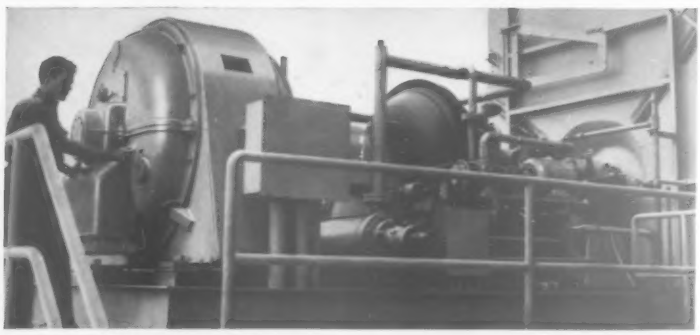
First Quarter, 1950



Three 2,000-hp, two pole Allis-Chalmers motors drive these three 1190 gpm, 1750 lbs psi, A-C boiler feed pumps.

At The Dayton Power and Light Compan

for BIG auxiliaries, where reliability comes first



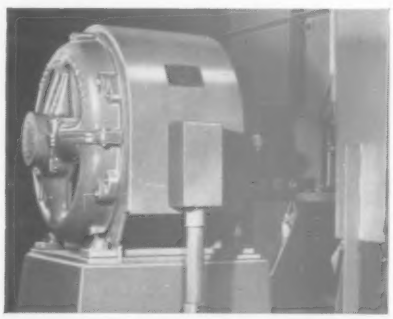
Induced draft fan being driven through hydraulic coupling by 1200-hp Allis-Chalmers outdoor splash-proof cage motor.

IN THE SPARKLING new O. H. Hutchings Station of The Dayton Power and Light Company, Dayton, Ohio, you'll see Allis-Chalmers motors at all vital points. These motors represent only a part of the A-C equipment installed at Dayton, and only a small part of the broad line of products Allis-Chalmers builds for the electric power industry.

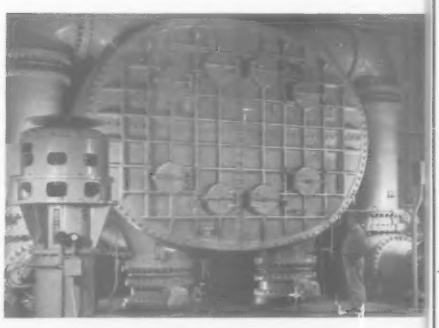
If you intend to modernize or enlarge your facilities remember that Allis-Chalmers motors — in fact all A-C equipment for power — offer: continuity of operation; a wide range of types and sizes; and low maintenance. Call your nearby Allis-Chalmers Sales Office, or write direct for more information about the equipment shown here. A-3032

Allis-Chalmers, 848-A S. 70th St.
Milwaukee, Wisconsin

Six of these 250-hp cage motors are used for pulverizer mill and fan drives.

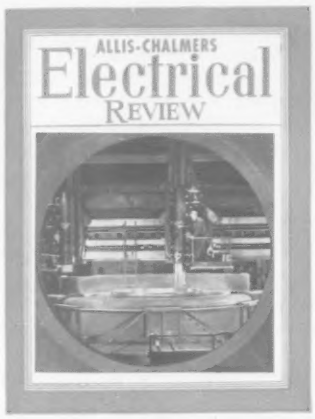


This 400-hp Allis-Chalmers cage motor is driving a forced draft fan.



Each condenser furnished with two 250-hp vertical motors and 21,650-gpm pumps . . . all by A-C.

ALLIS-CHALMERS



STEAM TURBINE exhaust ring is shown being machined. Picture was taken through the 96-inch opening of an identical ring. Weighing 65 tons each, rings are parts of the low pressure cylinder for an 80,000-kw, 1,800-rpm turbine now under construction.

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Allis-Chalmers

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ALLIS-CHALMERS Electrical REVIEW

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Contents

Hermetically Sealed Transformers Are Here!..... 4
W. M. TERRY, JR.

Push-Button Testing of Power Transformers..... 10
W. C. SEALEY and S. L. FOSTER

Phasing Out Switchgear Connections..... 18
R. E. BURLINGAME

Is More Inertia the Answer?..... 22
G. BYBERG and V. J. EGAN

New Blood for Old Switchgear..... 28
C. J. TEASLEY

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HERMETICALLY *Sealed* TRANSFORMERS Are Here!

WILLIAM M. TERRY, JR.
Development Engineering Section
Allis-Chalmers Mfg. Co.
Pittsburgh, Pa.

Author discusses the pros and cons of newly developed large gas-filled transformers.

THE RECENT DEVELOPMENT of sealed dry type transformers is bringing forth a great deal of interest among transmission and distribution engineers all over the country. Probably because they are so new, there are some popular misconceptions about the characteristics of the units. Our purpose here is to outline these characteristics, the advantages and disadvantages of this new class of equipment, and to point to what we may expect from it in the future.

First of all, let us define what we mean by "sealed dry type transformers." These are transformers whose core and coil elements are hermetically sealed in an inert gas; the gas serving as dielectric medium and as a means of dissipating the heat losses released internally. Our discussion will be confined to sealed dry type transformers 150-kva and larger, although conditions and problems are similar for smaller units.

At the outset, the transformer was an air-cooled device. The first oil-insulated transformers made their appearance in the 1880s and immediately became the standard and accepted way of transforming alternating current electrical energy. However, in the 1930s, two new types of units made their appearance. One of these was in the non-inflammable Askarel liquid-filled transformer, and the second, which was not really new at all, was the modern Class B insulated, open, dry type transformer. Both of these units have been widely accepted by the industry and their installed operating record is a successful one.

The major impetus to both Askarel liquid-filled units and Class B dry type installations case is a result of World War II. Thousands of expanding war industries required enormous amounts of electrical energy. Load center transformers and complete package substations became the most practical and economical method of bringing energy to the machines. The Class B dry type transformer was chosen for many applications because it reduced very greatly the chances of explosion during fault conditions, and in addition it could be placed most anywhere, even in unprotected locations directly over the heads of workers. It also has another advantage over Askarel liquid-filled units in that special precautions do not have to be taken to vent possible noxious fumes to the outside atmosphere during fault conditions.

Based on a critical study of the merits and disadvantages of Class B open dry type transformers, and on field service records of the many thousands of units shipped during the war, transformer engineers turned to the next step in improving transformers — sealing them completely. This had been standard practice for years with instrument as well as with almost all small transformers, using an impregnating compound. In the large sizes, where heat losses are great, solid impregnation of transformers is not practical.

The use of an inert gas under pressure as a dependable insulating medium had already achieved wide acceptance, having been used for many years in the construction of high voltage cable, transmitting capacitors, turbo-generators, as well as in other equipment. Therefore thinking naturally turned to the possibilities of using inert gases in sealed transformers.

Insulation was the problem

To make practical use of the advantages of sealed inert gas construction it was necessary to have high temperature insulating materials available. Fortunately, during 1944, silicone resins and insulations became available in volume, and provided the basic materials to withstand the higher operating temperatures of the sealed unit, so that economical and somewhat similar size and weights could be maintained. Silicone resins and their combination with Class C inorganic materials are designated as Class H insulations, and defined in the Introduction to AIEE Standards No. 1.

At the present time, until more is known about the behavior of Class B material in inert gases at relatively high temperatures, only two classes of materials are available to choose from. These are Class C inorganic materials comprising porcelain, glass, mica, asbestos, etc., and the new Class H silicone-inorganic combinations. Silicones are not entirely inorganic compounds. Silicon in silicones replaces most of the conventional carbon in organic materials, making them act in most instances like inorganic compounds, giving them exceptional heat resistance and a measure of mechanical flexibility.

Until extensive tests have been completed, the tentative maximum temperature limit for continuous operation of Class H insulations has been set at 180 degrees C by the AIEE. To actually determine the aging of Class B and H

materials, as a preliminary to setting maximum operating temperature limits, the AIEE Transformer Committee has appointed a working group to conduct actual aging tests and to report the results. Tests are being made by laboratories of four electrical equipment and insulation manufacturers. Aging tests are being conducted in an air atmosphere. Characteristics to be determined are the decrease in insulation resistance and dielectric strength versus time at various aging temperatures. In addition, power factor will also be measured. Pilot tests are in progress now, and the main tests will require approximately two years for completion.

Based on present data, the 180 degree rise rating appears to be conservative, and it is anticipated that tests and experience will permit this limit to be raised with safety.

Silicones behave as organic materials in that they are subject to oxidation. If they are used in inert atmospheres protected from oxidation, considerably longer life will result. As temperature limits are increased, oxidation proceeds at increasingly rapid rates. The sealed dry type transformer whose insulation operates in an inert atmosphere thus has an advantage. The atmosphere surrounding the insulation is totally non-oxidizing, and is maintained that way throughout transformer life. This corresponds in some measure to the protection afforded in oil-filled transformers by sealed tanks or inert gas cushions over the oil to limit oxidation of the transformer oil.

Since it appears that the majority of Class H insulated transformers in sizes 150 kva and larger will be sealed tank units, studies at present are directed toward insulation aging and operation in inert gas. Other gases such as the freons and sulphur hexafluoride show promise for use as insulating and cooling mediums. For instance, sulphur hexafluoride, at a pressure of two to four atmospheres, exhibits 60 cycle and impulse voltage strengths comparable to transformer oil. However, not enough is known of their characteristics or their chemical reactions with other transformer insulating materials to make them commercially practical at present.

Nitrogen insures long insulation life

To determine comparative aging effects in both nitrogen and air of several common Class H materials, tests are also being conducted on insulation samples similar to those of the AIEE pilot aging tests. These samples are composed of bare rectangular copper magnet wire straps separated by the thickness of insulation under test. These straps are stacked in multiple thickness and clamped under a constant pressure between retainer plates. The unit assembly is then given a double silicone varnish treatment similar to that given an actual transformer structure. Each assembly may be used for non-

THIS 300-KVA SEALED nitrogen-filled transformer is installed underground in an eastern city. Water, mud or dirt will not affect its operation. Pressure gauge shows whether tank has remained sealed.

destructive power factor and insulation resistance measurements, and for destructive dielectric tests to failure using as many test points per assembly as are required.

To graphically illustrate the effects of aging in air and nitrogen, Figures 1, 2, and 3 show graphs of dielectric strength, insulation resistance, and power factor, respectively, versus aging time in days, of samples aged in air and in dry nitrogen at a temperature of 349 degrees C (660 degrees F) for periods of time up to 45 days for silicone-treated asbestos paper. Tests are still in progress at this temperature and at lower temperatures. The 349 degrees C point is used to illustrate that amazing retentions of original characteristics are maintained even at such high temperatures. Operation at such a high value also greatly accelerates aging. Considering Figure 1, the curves show only a 14.5 percent decrease in dielectric strength for silicone-treated asbestos aged in nitro-

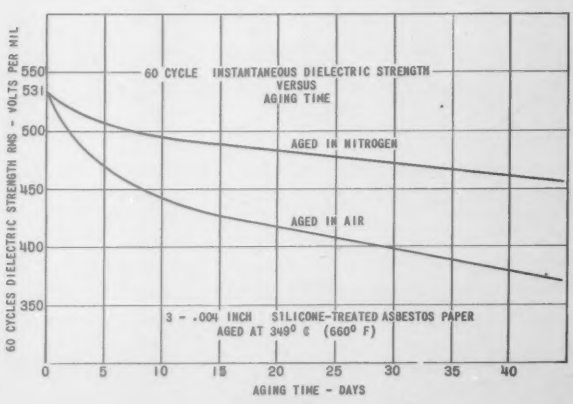


FIGURE 1

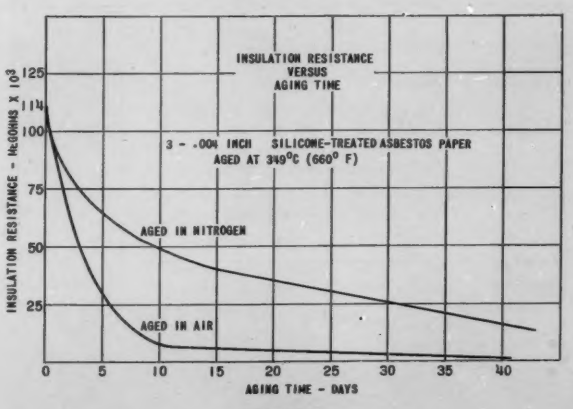


FIGURE 2

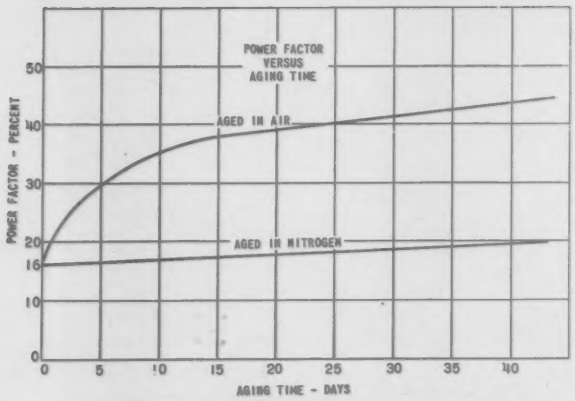


FIGURE 3

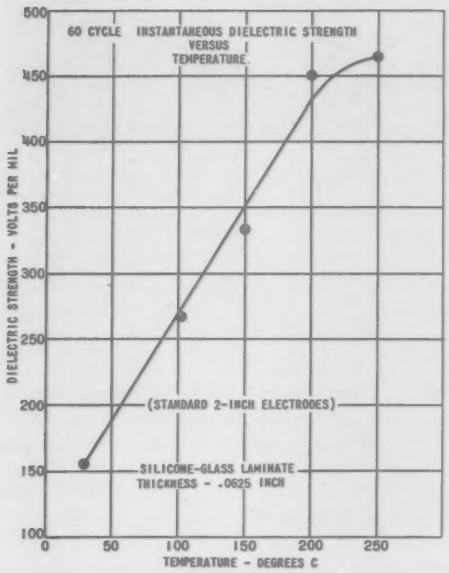


FIGURE 4

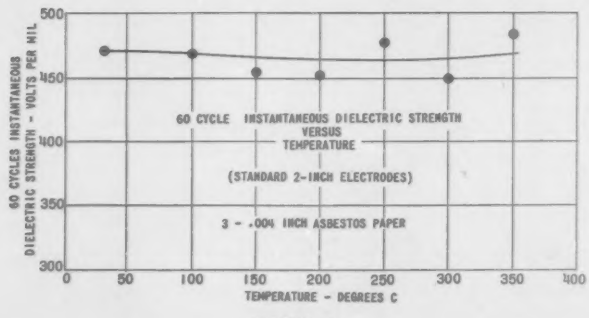


FIGURE 5

gen, versus a 31 percent decrease in dielectric strength for aging in air after 45 days at temperature. Under test, the samples are aged in ovens, removed at periodic intervals, cooled to room temperature, tested, and returned to the ovens.

To complete our knowledge of insulation characteristics, the dielectric strength must be known in the expected operating temperature range. Figures 4 and 5 show how the instantaneous 60-cycle dielectric strength of silicone glass laminate and asbestos paper varies with temperatures up to 350 degrees C. Dielectric strength is approximately equal to, or greater than, the 60-cycle strength at room temperature throughout this range. Thus in the useful operating range of temperature, Class H insulations exhibit maximum dielectric strength. This is in direct contrast to organic insulations in oil or Askarel, which show steadily decreasing dielectric strength with increasing temperature.

Increased costs are justified

The silicone insulating resins are several times more costly at present than the organic resins used as a base for Class B insulations. Due to this increased cost of Class C and Class H insulation in sealed dry type units, their cost is approximately 20 percent higher than Class B insulated types at present. It is expected that as the use of silicones increases, resulting in increased volume of manufacture, costs will undoubtedly be reduced. However, silicones can be economically justified today in many applications, due to their greatly increased temperature resistance.

Design characteristics of sealed dry type Class H insulated transformers differ from conventional Class B insulated open dry type transformers. Because of the exclusive use of Class C and Class H insulations, and because the transformer operates in a sealed inert nitrogen atmosphere where its losses are dissipated through radiation and natural internal convective gas flow, both the average copper temperature and the hottest spot temperature can be much higher.

One of the most important design advantages in a sealed transformer is that the original insulation clearances designed into the transformer are maintained throughout the life of the unit. The effects of humidity, water vapor, dirt, and other contaminating atmospheres are eliminated from design considerations. To a transformer designer this is quite an advantage. In conventional open dry type transformers, insulation clearances are based on the premise that a reasonable amount of contamination due to dirt, moisture, etc., is to be expected, and that the transformer should continue to operate satisfactorily under these conditions. The term, "a reasonable amount of contamination," has been the subject of widely varying interpretations. Contaminating conditions may sometimes be worse than expected and, should trouble develop, the question may arise whether the design is at fault or whether unusual operating conditions are the cause. In the sealed dry type transformer, conditions are controlled, as in any sealed liquid-filled transformer, and this problem does not arise.

Impulse strength is same as air

Dry nitrogen gas at low pressures has approximately the same impulse strength as dry air at atmospheric pressure. There is therefore not too much hope that impulse levels of either Class B or Class H insulated dry type transformers will be raised appreciably above the present levels as given in ASA Transformer Standards, which give an impulse strength of 50 kv for the 15-kv class dry type units as compared to a full

wave level of 110 kv for the 15-kv class liquid-filled power apparatus. It is not impossible to meet liquid filled impulse levels with dry type apparatus, but transformer design economics would not justify the changes required, and in addition the basic 60-cycle levels would have been raised to a point where, on a straight 60-cycle basis, the units would be insulated for more than 15-kv class. Although impulse levels are lower for dry types, 60-cycle dielectric test levels are comparable, with a 31-kv level for dry types as compared to 34 kv for liquid-filled apparatus.

Another important advantage is that oxidation of copper conductors is eliminated in sealed inert gas-filled equipment. At the high temperatures used, this is a factor, as oxidation reduces effective conductor area, resulting in greater losses and heating, and further increasing copper oxidation.

The application range of the sealed dry type transformer is wider than that of the conventional open dry type. They may be used in any location, regardless of atmospheric or moisture conditions. One obvious application, and the one for which the first units have been built, are as submersible network transformers where flooding of vaults or manholes regularly occurs. Other obvious good applications include their use as load center transformers in particularly dirty industrial locations, or for station and powerhouse auxiliaries where atmospheric contamination is likely to make the use of open dry type equipment costly and hazardous. Location can be made without concern for hazard to nearby personnel, as the core and coil elements are hermetically sealed in dry nitrogen, and the possibility of explosion is completely eliminated.

Of major importance on some jobs is the reduction in maintenance as compared to the open dry type transformer. Periodic maintenance can be reduced to a check only of the external case and bushings. The windings are completely protected from foreign matter. If care is taken to prevent mechanical damage to the windings, the core and coil element should not have to be removed from the tank throughout the life of the transformer. Even the periodic filtering necessary in either oil or Askarel liquid-filled units is eliminated. In addition, if the unit should be stored or unenergized for a period of time, no special precautions other than a check of the pressure gauge have to be taken before putting the transformer back into service. With the present burden of high labor costs,

APPROXIMATE WEIGHTS AND DIMENSIONS — TABLE I

1,000-Kva, Three-Phase, 60-Cycle, 15-Kv Class, 5% Impedance

	Askarel Liquid Filled	Open Dry Type Class B	Sealed Dry Type Class H
Floor Area Required*	80" x 51"	152" x 54"	89" x 40"
Height	88"	98½"	96"
Total Weight	18,700 Lbs	13,000 Lbs	12,000 Lbs

500-Kva, Three-Phase, 60-Cycle, 15-Kv Class, 5% Impedance

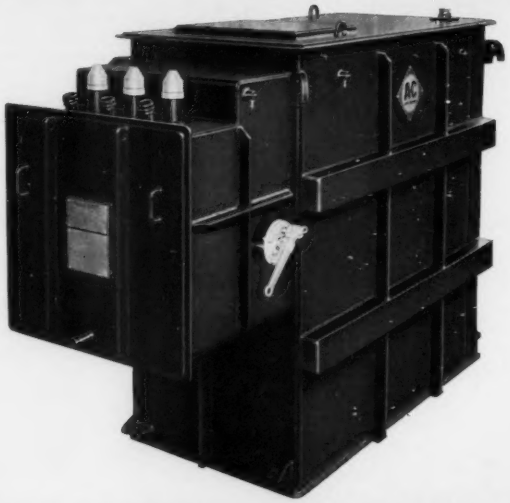
	Askarel Liquid Filled	Open Dry Type Class B	Sealed Dry Type Class H
Floor Area Required*	71" x 40"	133" x 49"	84" x 38"
Height	71"	100"	87"
Total Weight	11,300 Lbs	7,000 Lbs	8,000 Lbs

300-Kva, Three-Phase, 60-Cycle, 15-Kv Class, 5% Impedance

	Askarel Liquid Filled	Open Dry Type Class B	Sealed Dry Type Class H
Floor Area Required*	64" x 38"	100" x 40"	78" x 36"
Height	66"	115"	87"
Total Weight	9,300 Lbs	5,500 Lbs	6,500 Lbs

*Length dimension is dimension over high voltage and low voltage bushing and does not include high voltage switch or low voltage network protector.

APPROXIMATE WEIGHTS and dimensions of Askarel liquid-filled, conventional Class B dry type and the sealed Class H dry type transformers reflect the space economies available with the new gas-filled units.



GAS-FILLED TRANSFORMERS are built to withstand dirt, moisture and other harmful atmospheric conditions. Cover, handhole cover and high voltage switch are welded gas-tight to prevent possibility of breathing.

DIMENSION DATA — TABLE II

Floor Area Required:	83" x 44" (Main Transformer) 45½" x 117" (over high voltage switch and low voltage throat)
Height:	83" over lifting hooks
Weight:	9,000 Lbs Total, including tap changer and high voltage switch

No-load tap changer arranged for external operation under sealed pipe plug.

Radiators:	None
Core:	Preferred oriented steel
Tank:	Welded gas-tight
Gas:	Dry nitrogen

TEST CHARACTERISTICS

Core Loss:	1,296 Watts
Total Loss:	4,846 Watts
Impedance:	9.25 Percent
Efficiency Full Load:	98.4 Percent

	100% Load	125% Load	150% Load
Average LV Copper Rise by Resistance	97.2°C	124.8°C	159.8°C
Hottest-Spot Copper Rise — LV	109.0°C	145.0°C	189.0°C
Average HV Copper Rise by Resistance	82.7°C	110.5°C	142.3°C
Hottest-Spot Copper Rise — HV (Est.)	93.0°C	130.0°C	172.0°C
Core Temperature Rise	120.5°C	142.0°C	170.0°C
Top Gas Temperature Rise	69.5°C	89.0°C	113.0°C
Hottest-Spot External Tank Rise	33.5°C	41.0°C	53.0°C
Gas Temperature Rise Top of HV Ducts	96.5°C	126.5°C	163.5°C

PHYSICAL CHARACTERISTICS and test data for a 300-kva, three-phase, 60-cycle gas-filled transformer show its performance under varying load conditions. Transformers can be installed anywhere.

the sealed dry type transformer with its elimination of special handling and reduced maintenance throughout its service life should be investigated for future applications where explosion-proof and non-inflammable transformers would be required.

Analyzing the pros and cons

Figure 6 gives a comparison of losses between sealed dry type, open dry type, and Askarel-filled transformers for the 300, 500, and 1,000 kva sizes. Both core and total losses in the sealed dry type are approximately 15 percent greater than Askarel-filled losses, as compared to approximately a 24 percent increase in total losses for the Class B dry type. The increase in losses for both the sealed and ventilated dry type transformer is due primarily to the larger insulation clearances required for operation in nitrogen or air.

Table I shows a comparison of dimensions and weights of these same three types of transformers. The floor area required for the sealed dry type compares very favorably with liquid-filled apparatus, while the heights of the sealed dry types are approximately 15 inches greater. The tank of the sealed dry type is larger than for liquid-filled, but all cooling tubes or radiators are eliminated. The plain tank shell will contribute to ease of cleaning and painting. The external paint used is a special enamel designed to withstand the increased tank temperatures of the sealed dry type. The weight of the sealed dry type is approximately 70 percent of the total Askarel liquid-filled unit weight. The omission of liquid is the main contributing factor.

Insulation clearances are such that if a gas leak should occur, and air enter the case, the unit will continue to operate satisfactorily without the possibility of failure. A built-in pressure gauge provides a quick check on tank tightness.

The primary disadvantages of the sealed dry type transformer are common to both dry types. The impulse voltage strength of the windings is only about 50 percent that of liquid-filled apparatus, and necessary protection is required to limit incoming voltage surges within safe limits if they do occur. In common with all dry type transformer apparatus, audio noise levels are greater than for equivalent liquid-filled units.

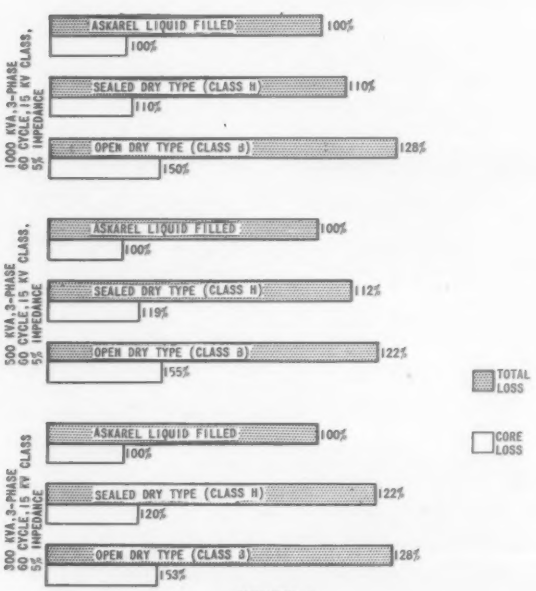

1000 KVA, 3-PHASE 60 CYCLE, 15 KV CLASS, 5% IMPEDANCE
ASKAREL LIQUID FILLED 100%
100%
SEALED DRY TYPE (CLASS H) 110%
110%
OPEN DRY TYPE (CLASS B) 128%
150%
500 KVA, 3-PHASE 60 CYCLE, 15 KV CLASS, 5% IMPEDANCE
ASKAREL LIQUID FILLED 100%
100%
SEALED DRY TYPE (CLASS H) 112%
119%
OPEN DRY TYPE (CLASS B) 122%
155%
300 KVA, 3-PHASE 60 CYCLE, 15 KV CLASS 5% IMPEDANCE
ASKAREL LIQUID FILLED 100%
100%
SEALED DRY TYPE (CLASS H) 122%
120%
OPEN DRY TYPE (CLASS B) 128%
153%
TOTAL LOSS
CORE LOSS

FIGURE 6

Tests show conservative ratings

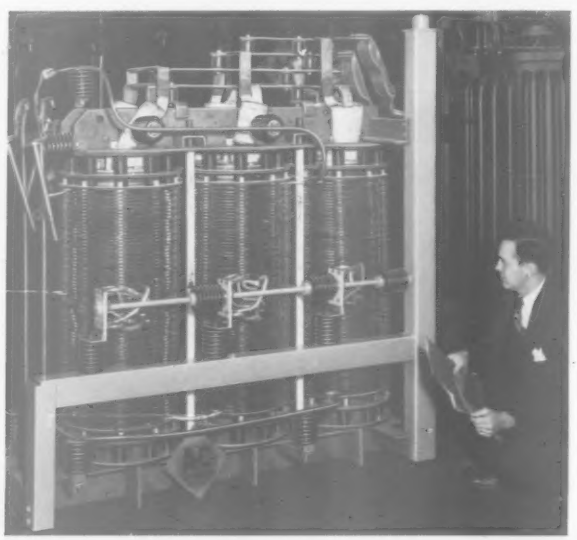
To complete the performance picture, actual test data is presented in Table II for a typical 300-kva, three-phase, 60-cycle, sealed, submersible dry type network transformer with 12,000-v, delta-connected high voltage and 216-v Y-connected low voltage. The transformer is filled with dry nitrogen gas to a pressure of ½-pound gauge at 25 degrees C. All insulating material used in the transformer is either Class C or Class H. The assembled coils are silicone varnish treated in a two-dip process. In addition, this transformer is constructed with a no-load tap changer, which is operated by removing a pipe plug on the top of the unit, operating the connecting mechanism, and replacing the pipe plug, thus resealing the transformer.

The core loss of the transformer is 1,296 watts with a total loss at full load of 4,846 watts, resulting in a full load efficiency of 98.4 percent. On heat run at 100 percent load, the average low voltage copper rise by resistance was 97.2 degrees C with a hottest spot copper rise of 109 degrees as measured by thermocouples embedded in the low voltage winding. The high voltage winding temperature rises are 82.7 degrees C average rise and 93 degrees hottest spot rise. When the load is increased to 150 percent the average copper rise of the low voltage winding increases to 159.8 degrees C with a measured hottest spot rise of 189 degrees.

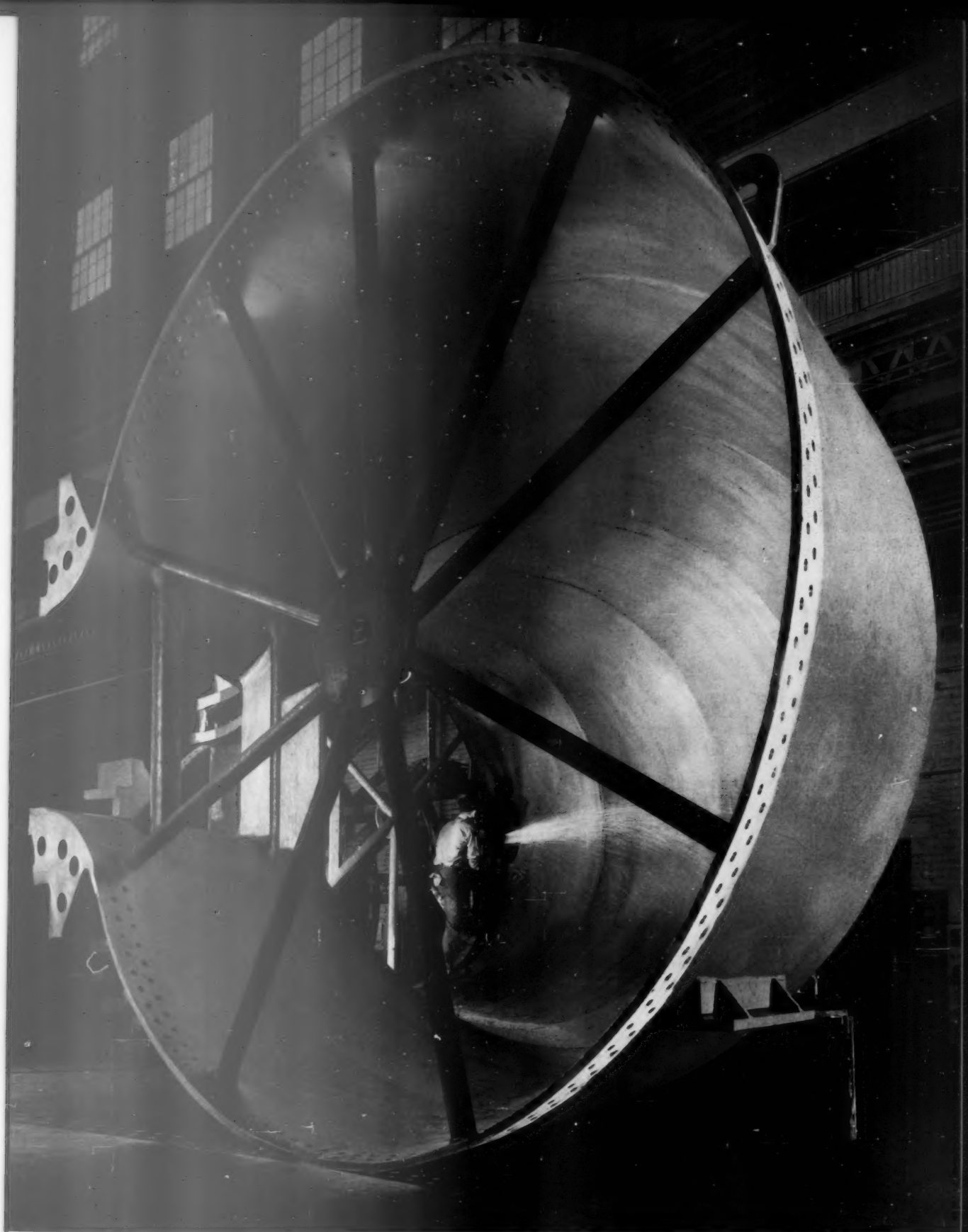
These transformers have been rated very conservatively. Operating in an inert atmosphere, it is expected that they will be able to carry 150 percent load continuously for a full normal transformer life. The hottest spot copper rise at 150 percent load exceeds the average rise by only 19 percent. Both high and low voltage windings are well ventilated.

The ability of sealed dry type transformers to carry overloads is expected to be much greater than the Class B insulated open dry type transformer, since operation in an inert gas excludes oxidation aging of the insulation.

Inert gas-filled transformers are a new tool for both utility and industrial power system engineers. They have distinct advantages as well as disadvantages. While they are no cure-all, they do offer much promise for the future.



COMPLETE CORE AND COIL element shows low voltage bus mounted on top of core and coil assembly. Porcelain insulators provide minimum lead reactance yet maintain ample electrical clearances.



SPIRAL CASING SECTION will be a part of the first of three hydraulic turbines under construction for Bull Shoals Dam in northern Arkansas. Rated 62,000-hp, 190-foot head, 128.6-rpm, turbines will be completed and installed in 1951. Inner surfaces of the inch thick plate are being ground to insure tightness after spider web bracing is removed and sections are riveted at site. Balance of joints are all-welded.

Push Button Testing of POWER TRANSFORMERS

by **W. C. SEALEY**
Engineer-in-Charge Design
and

S. L. FOSTER
Design Engineer
Transformer Section
Allis-Chalmers Mfg. Co.
Milwaukee, Wis.

"Dream" test floor for large transformers eliminates wasted effort and delays. One-stop testing speeds production.

TESTING POWER TRANSFORMERS for desired characteristics and whether or not they meet guarantees or are suitable for service is as important as the design, construction, and application of such equipment. Because they protect both the manufacturer and user, tests must be all-inclusive and conducted in a manner and with equipment which assure accurate, efficient, and uninterrupted testing.

Each transformer is tested for the following characteristics:

Ratio	Load loss and impedance
Resistance	Heat run
Polarity	High potential
No-load loss and exciting current	Induced voltage
	Impulse

These tests are standard and are conducted wherever transformers are made. The only difference lies in the manner in which they are conducted.

The need for improved test equipment and faster, more efficient testing procedures is a direct result of the tremendously increased transformer production volume actuated by post-war demand. Production methods have been modernized so that now even the largest transformers are assembly-line produced. Testing methods had to be streamlined to keep abreast of production. In addition, many power transformers are tested in the presence of inspectors representing the user whose valuable time must be appreciated and considered.

Centralized testing proves best

Elimination of cumbersome and time-consuming testing procedures to match modernized, stepped-up production had been under consideration for several years. Design, building, and application of the needed equipment and technique, however, was completed only recently.

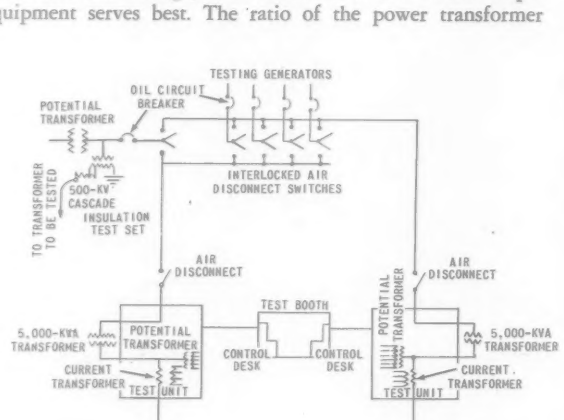
The new power transformer test floor meets all of the requirements of transformer production and application (Figure 1). It is arranged so that all tests, except for impulse, can be made in one location. The impulse test can be made by a short move of the transformer to an immediately adjacent location. The test floor is located at the end of the assembly aisle, next to the shipping area where transformers are loaded on railroad cars for shipment.

The testing installation provides two identical testing units each connected to one end of the test bus. Two vertical, three-phase buses permit connecting two transformers to the test buses. Air disconnect switches provide for sectionalizing the test bus so that two transformers may be tested simultaneously, one for each test unit, each of which has its own control desk with test unit and meter controls.

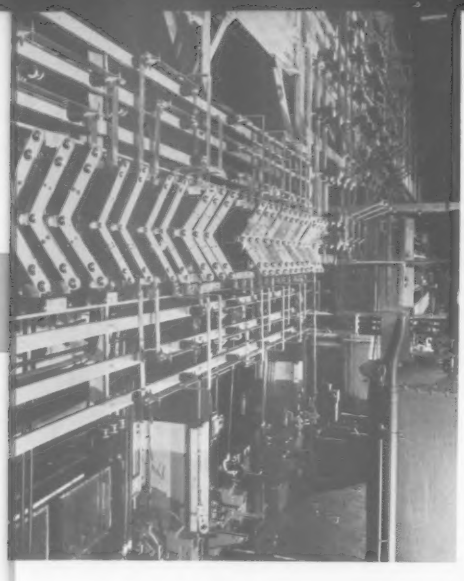
New method is simple

Advantages of this type of testing arrangement and procedure are evident. All tests are completed in one place and in one continuous operation without disrupting production.

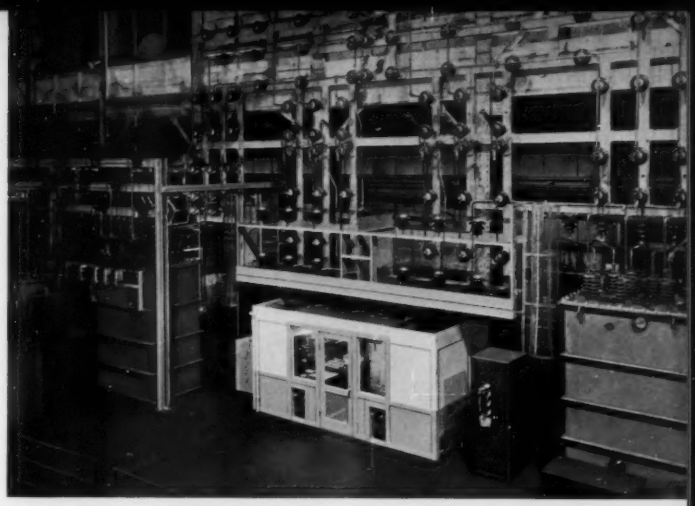
Ratio tests—When the completed transformer reaches the test floor it is first tested for ratio, resistance, and polarity. These are low voltage, low current tests for which simple equipment serves best. The ratio of the power transformer



LINE DIAGRAM of power circuit shows the interlocking arrangement and methods of measuring used to simplify transformer testing. **(Figure 1)**



TESTING BUSWORK includes latest safety features and interlocks. Test cable terminals at right are inaccessible when energized.



OPERATING EQUIPMENT is centrally located to eliminate wasted motion in transformer testing. Test facilities are between assembly floor and shipping areas to provide uninterrupted production. Uni-directional flow has reduced test set-up time by 60 percent. **(Figure 2)**

is determined by applying low 60-cycle voltage to one winding and connecting a voltmeter across the terminals of the other winding. Power for this purpose is furnished by a 12-kva, 0-550-volt continuously variable tapped transformer, the primary of which is connected to the shop supply line. The variable voltage transformer, its output leads and connections for voltmeters are mounted on the left side of the control desk shown in Figure 2.

Polarity and resistance test—Polarity of single-phase windings may be determined by connecting adjacent terminals of the two windings together and connecting a voltmeter across the other two terminals. The phase relations of a three-phase transformer is determined in similar fashion by measuring voltages between terminals.

The resistance of a transformer winding is measured by the drop of potential method using a d-c ammeter and voltmeter and a power source. It may consist of either of two different storage batteries with a rheostat in series for adjusting the current. One is a 150-volt battery used to deliver currents up to 20 amperes, the other is a 6-volt battery for currents up to 100 amperes. The constant voltage of a storage battery makes it ideal as a power source for resistance measurements. This equipment may also be used for determining transformer polarity by the d-c method.

Testing equipment for no-load loss, exciting current, load loss and impedance measurement requires a kva rating which may be as large as 20 percent of the kva rating of the transformer being tested. The no-load loss test requires a voltage equal to rated voltage of the transformer. The load loss test requires a current equal to the rated current of the transformer. The common range in voltage required is from 100 to 100,000 volts while the common current range is from .1 to 1,500 amperes. The lower voltages and higher currents are needed for load loss tests. No-load tests require higher voltages and lower currents.

Interlock switches vary connections

The adjustable voltage power source for testing transformer losses is any one of several a-c generators, the largest of which is rated 40,000 kva, 3 phase, 60 cycles, 13,800 volts. Any one of the testing generators may be connected to a test unit by air disconnect switches located on the test floor. These switches are interlocked to prevent two machines from being thrown on the same bus simultaneously.

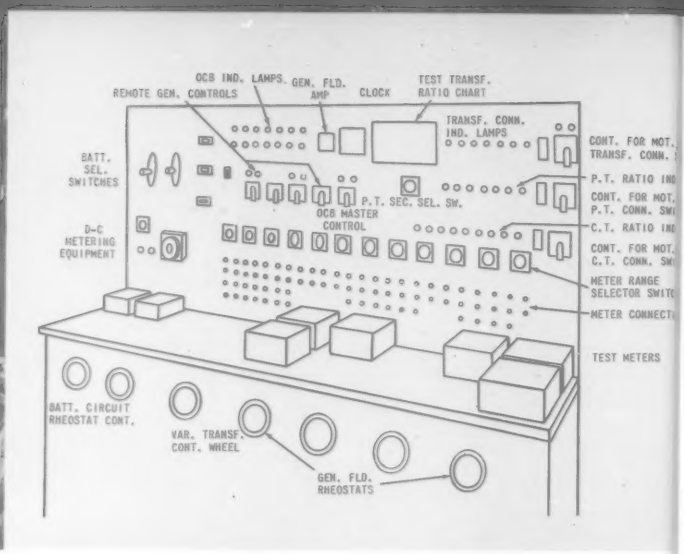
The test unit is an oil-filled tank containing motor-operated switches and instrument transformers. Two of the motor-operated switches operate to connect the low voltage side of three 5,000-kva, single-phase testing transformers to a generator and the high voltage side of the testing transformers to the testing buses mounted on the wall of the test floor. The following connections between testing transformers, generators and buses are obtained by these two switches:

1. Generator to bus with no testing transformer windings in the circuit.
2. Low voltage windings of testing transformer in delta to generator; high voltage windings of testing transformer in delta to testing bus.
3. Low voltage delta to generator; high voltage Y to testing bus.
4. Low voltage Y to generator; high voltage delta to testing bus.
5. Low voltage, single-phase, two transformers in parallel to generator; high voltage, single-phase, two transformers in parallel to testing bus.
6. Low voltage, single-phase, two transformers in parallel to generator; high voltage winding two transformers in series to bus.

The rated full capacity voltages of the low voltage windings are: 2,300/4,600/9,200 volts. The rated full capacity voltages of the high voltage windings are: 13,750/27,500/55,000 volts. The low voltage and high voltage windings of each transformer are brought out of the case through eight bushings each. Plug-type connectors on the bushings are used to obtain these series parallel voltages, and since the maximum current for any plug is approximately 500 amperes, the plugs are small enough for convenient changing of connections.

By use of the motor-operated switches and series parallel plug connections of the high voltage windings, the following three-phase voltages may be obtained on the test buses when 9,200 volts is supplied by the generator to the incoming side of the test unit:

95,260 volts	23,815 volts
55,000 volts	15,875 volts
47,630 volts	13,750 volts
31,750 volts	9,200 volts
27,500 volts	7,940 volts



CONTROL BOARD condenses testing and control equipment so that it can be operated conveniently from one position. All instrument and power transformer connections are indicated for immediate observation. Phantom diagram identifies test and control apparatus. **(Figure 3)**

Field rheostats adjust generator voltage

Voltages in between these voltages and lower voltages may be obtained by adjusting the generator field rheostats. (See Figure 1.) Still lower voltages may be had by connecting the generator windings for lower voltages and by adjusting the field rheostats. In order to provide a wide range of adjustment of generator voltage with vernier control of voltage, field rheostats having the following ohmic resistance and numbers of steps are used:

1.25 ohms	60 steps	20 ohms	124 steps
4 ohms	60 steps	64 ohms	124 steps

At the lowest generator voltage all rheostats are in the circuit. The voltage is adjusted to a slightly lower value than required, using the rheostat of highest resistance, and then increased to the exact desired voltage, using the 1.25-ohm rheostat as a vernier. This provides smooth control without the necessity of a fine touch on the rheostat handle.

The outgoing leads to the test unit are connected to test buses through air disconnect switches. Flexible cable connections are made from the test buses to the bushings of the transformer being tested.

The test unit also houses the oil-immersed current transformers connected in series with each of the output leads of the test unit, as shown in Figure 1. The following ratios are provided by the current transformers:

.5	50	to 5
1.5	150	
5	500	
15	1500	

The current transformer ratio is changed by a motor-operated tap changer which, if desired, may be operated under load. The tap changer is controlled from the control desk. When used with a 5/10 ammeter a reading of at least 60 percent of full scale is obtained for the full range of current from .3 to 3,000 amperes.

Potential transformers (Figure 1) having the following ratios are also immersed in oil of the testing unit:

60,000	3,000	to 150 volts
18,000	1,500	
9,000	750	

These voltages are selected by means of the motor-operated switch controlled from the control desk. When used with a 75/150/300 voltmeter, a reading of at least 60 percent of full scale is obtainable for voltages ranging from 45 volts to 60,000 volts. Two potential transformers may be connected in series for a voltage of 120,000 volts, single phase or by addition of an external potential transformer, three-phase voltages up to 104,000 volts may be measured.

The current transformers and the potential transformers are made with close metering accuracy (R.C.F.=less than .15 percent) to insure accuracy of the loss measurements. The current transformers are connected in series with the output leads of the testing unit by a motor-operated tap changer. The terminals of the potential transformer are brought out through three bushings for connection, either to the output terminals of the test unit or, when conditions require, for connection directly to terminals of the transformer under test.

Testing controls conveniently grouped

The control switches for the motor-operated switches of the test unit are located on a desk which is provided with light position indicators. Meters are mounted on the flat portion of the control desk while terminals for meter connections, position indicator lights and switches to change the range of ammeters, voltmeters and wattmeters are located on the vertical panel of the desk. Rheostat handles for controlling the generator fields are set on the front of the control desk below the flat portion, which also supports the handle for operating the tap changer of the auto transformer to provide voltage adjustment for ratio measurement. Figure 3 shows the arrangement of the various testing elements.

The only manual connections to be made for loss tests are those to the transformers being tested. Such a test unit is particularly advantageous when a large number of impedance measurements must be made on transformers with a large number of taps, although it is a time-saver on any job.

Heat run tests—The test setup for short-circuit heat runs is exactly the same as for impedance tests except that the current supplied is greater than full load current.

High potential and induced voltage tests—Two 250-kv testing transformers connected in cascade are used to supply voltages up to 500 kv for high potential tests. As shown in

Figure 1, they are located immediately adjacent to the testing bus structure for convenience in making connections. The power for induced tests at 200 cycles is supplied from a 500-kva m-g set which can be connected to the incoming lines of the test unit, the same as the 60-cycle generators. For voltages up to 120 kv, induced voltage is applied through the 5,000-kva testing transformers in same manner as for loss tests. The higher voltages of 200-cycle power is applied through the 500-kv testing transformers.

Impulse tests—The three million-volt impulse testing equipment is located adjacent to the remainder of the test floor (Figure 4).

As an example of the facility of this test equipment the following typical example of a test on a large power transformer is given. The rating of the transformer to be tested is 40,000-kva, three-phase 138,000 volts grounded Y to 13,200 volts delta. The high voltage winding has 15 percent regulation by means of load-ratio-control equipment.

Check connections first

Before any other tests are made it is necessary to insure that the transformer windings are properly connected and have the proper ratio. The connection diagram and voltage ratios are given in Figure 5. A light three-wire insulated cable is run from the outlet studs of the 550-volt variable transformer to the high voltage bushings of the transformer. A pair of test leads are connected to studs at the end of test booth to bring the measuring voltage to permanently-wired meters on the control test desk. Readings taken to check the ratio of the transformer are shown in Figure 6.

A constant voltage is held on the high voltage side rather than any attempt being made to hold a constant voltage on the low voltage side as shown on connection diagram, since the test can be made more easily in this manner, and the ratio checked by the engineers will reveal the turn ratio the same as if constant voltage were held on the low voltage.

In order to check the phase relations of high and low voltage windings the bushings H_1 and X_1 are connected together and the voltage applied to H_1 - H_2 - H_3 as before. Voltage reading (Figure 7) indicates that the phase relation of the windings is as shown in Figure 5.

While the transformer is still at room temperature and no appreciable current has been passed through the windings to heat them, the cold resistance of the windings is taken.

Leads from the output studs from the battery circuit are connected to the bushings of the winding to be tested. Test leads are also connected to these bushings to measure the d-c voltage. These test leads are connected through a set of studs at the end of the control booth to a multi-ratio d-c voltmeter. An ammeter is permanently connected in series with the battery so that the d-c current can be measured. Figure 8 shows measurements made after the current was adjusted to a convenient value.

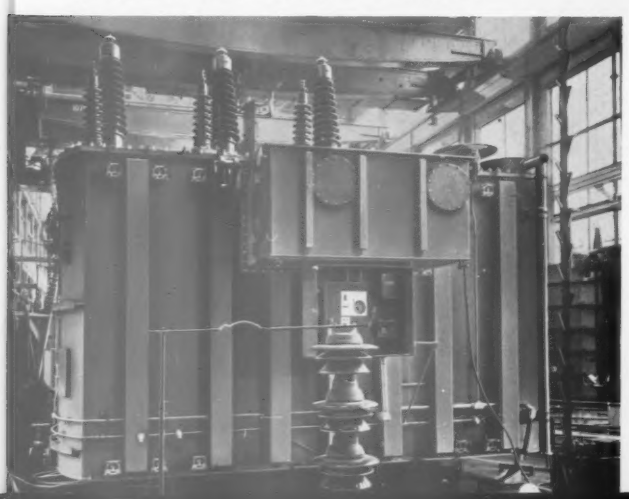
The rheostats in series with the battery allow the current to be set at different values for checking the measurement. By taking three points a very good check upon the accuracy of the testing is obtained.

Set-up eliminates delays

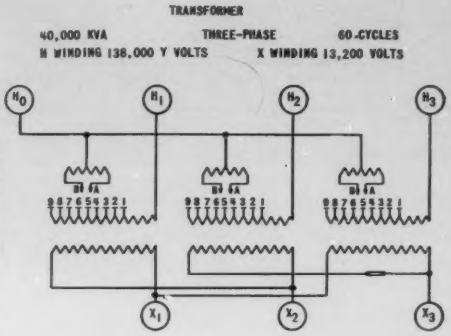
After the resistance and ratio have been taken with the light line directly from the control desk, the heavier cables from the output of the test unit are connected to the transformer. For the no-load loss test the cables are connected to the low voltage bushings of the transformer. The test unit is set for a delta-delta connection of the 5,000-kva testing transformers and the transformers connected 2,300 low voltage and 13,750 high voltage so that the test could be made from a 2,300-volt testing generator. The motor-operated ratio switch on the potential transformer is set for 120:1 ratio. Since the exciting current of this size power transformer is usually less than three percent (or 52.5 amperes for this transformer), a 50:5 ratio is selected on the current transformer selector switch.

The field of the generator is reduced to a low value so as to bring the voltage up gradually at first. The air disconnect switches are closed to place the generator on the input bus to the testing unit and the air disconnect switches are also closed to connect the transformer under test to the ouput of the testing unit, as shown in Figure 1. The final connection is closed by a remotely controlled oil circuit breaker on the input of the testing unit. This is closed by the operator from a control switch on the control desk.

IMPULSE TEST equipment can be used for tests up to three million volts. It is adjacent to the 60-cycle test apparatus. **(Figure 4)**

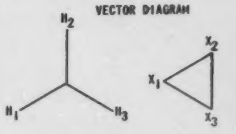


TRANSFORMER rating and connections of a 40,000-kva, 3-phase, 60-cycle unit tested with new test equipment. **(Fig. 5)**



H WINDING				
Volts H_1 to H_2 to H_3	Amps.	Load Tap Changer		
		Pos. No.	A On	B On
152,000	152	17	9	9
150,500	154	16	8	9
149,200	155	15	8	8
147,900	156	14	7	8
146,630	158	13	7	7
145,300	159	12	6	7
144,000	160	11	6	6
142,700	162	10	5	6
141,450	163	9	5	5
140,300	165	8	4	5
139,100	166	7	4	4
138,000	168	6	3	4
136,700	169	5	3	3
135,300	171	4	2	3
133,900	173	3	2	2
132,500	174	2	1	2
131,000	176	1	1	1

VECTOR DIAGRAM



X WINDING	
Volts X_1 to X_2 to X_3	Amperes
13,200	1,750

FIGURE 5

RATIO												
POS.	VOLTS $H_2 - H_0 - H_4$					VOLTS $X_1 - X_2 - X_3$						
1	400					40.7						
2	400					40.3						
3	400					40.0						
4	400					39.5						
5	400					39.2						
6	400					38.7						
7	400					38.3						
8	400					37.9						
9	400					37.5						
10	400					37.1						
11	400					36.9						
12	400					36.5						
13	400					36.1						
14	400					35.9						
15	400					35.5						
16	400					35.1						
17	400					34.9						

FIGURE 6

ALLIS-CHALMERS MANUFACTURING COMPANY
TRANSFORMER TEST RECORD

COLD RESISTANCES 25°C °C. TOP OIL °C. BOT. OIL °C. HEATER ON TANK °C.

	H. V. WINDING			L. V. WINDING			WINDING			WINDING		
	VOLTS	AMPS.	OHMS	VOLTS	AMPS.	OHMS	VOLTS	AMPS.	OHMS	VOLTS	AMPS.	OHMS
INST. NO.												
INST. SCALE												
CONNECTION				WINDING HV 131,000 VOLT								
BETWEEN	$H_1 - H_2$			$H_2 - H_3$			$H_1 - H_3$					
	9.12	5.40	1.69	9.10	5.37	1.69	9.09	5.36	1.70			
	7.83	4.63	1.69	8.11	4.80	1.69	7.80	4.61	1.69			
	6.91	4.09	1.69	7.10	4.20	1.69	6.94	4.10	1.69			

HOT RESISTANCES °C. TOP OIL °C. BOT. OIL °C. HEATER ON TANK °C.

Comm. between				WINDING HV 138,000 VOLT								
	$H_1 - H_2$			$H_2 - H_3$			$H_1 - H_3$					
	9.53	5.32	1.79	8.60	4.80	1.79	9.03	5.02	1.80			
	8.63	4.82	1.79	7.51	4.20	1.79	7.81	4.35	1.80			
	7.53	4.20	1.79	6.78	3.80	1.79	7.00	3.90	1.80			

FIGURE 8 (above and below)

ALLIS-CHALMERS MANUFACTURING COMPANY
TRANSFORMER TEST RECORD

COLD RESISTANCES 25°C °C. TOP OIL °C. BOT. OIL °C. HEATER ON TANK °C.

	H. V. WINDING			L. V. WINDING			WINDING			WINDING		
	VOLTS	AMPS.	OHMS	VOLTS	AMPS.	OHMS	VOLTS	AMPS.	OHMS	VOLTS	AMPS.	OHMS
INST. NO.												
INST. SCALE												
CONNECTION				WINDING HV 152,000 VOLT								
BETWEEN	$H_1 - H_2$			$H_2 - H_3$			$H_1 - H_3$					
	9.70	4.90	1.94	9.77	4.77	1.94	9.20	4.72	1.95			
	8.82	4.54	1.94	8.41	4.33	1.94	8.38	4.30	1.95			
	7.78	4.00	1.94	7.49	3.86	1.94	7.60	3.90	1.95			

HOT RESISTANCES °C. TOP OIL °C. BOT. OIL °C. HEATER ON TANK °C.

Comm. between				WINDING LV 132,000 VOLT								
	$X_1 - X_2$			$X_2 - X_3$			$X_1 - X_3$					
	.500	30.5	.016	.482	29.5	.016	.481	29.4	.016			
	.444	27.1	.016	.438	26.8	.016	.430	26.3	.016			
	.403	24.6	.016	.360	22.1	.016	.360	22.0	.016			

RATIO
POLARITY
CORE LOSS FROM AT CYCLES TRANSFORMER RATIO
IMPEDANCE FROM AT CYCLES TRANSFORMER RATIO

FIGURE 9

TRANS. NO.												
RATIO	120:1	120:1	50:5		120:1	50:5						
REG. IN SERIES												
	99.0	99.0	.71	-26x1	98.4	.97	+67x1					49.2
	104.5	104.5	.90	-40x1	104.0	1.22	+86x1					55.2
	110.0	110.0	1.12	-58x1	109.3	1.56	+110x1					64.2
	115.5	115.5	1.50	-83x1	114.6	2.02	+143x1					72.0
	121.0	121.0	1.90	-117.5x1	120.0	2.58	+186.5x1					82.8

FIGURE 7

REG. IN SERIES				POLARITY					
POS.	VOLTS $H_1 - H_2 - H_3$			VOLTS					
1		400		$H_2 - X_2$ 368					
1		400		$H_2 - X_2$ 401					
1		400		$H_2 - X_3$ 368					
1		400		$H_3 - X_3$ 368					

FIGURE 10

	VOLTS FLUX	VOLTS EXC	AMPS.	X_2 WATTS	VOLTS	AMPS.	X_2 WATTS	VOLTS	AMPS.	WATTS
INST. NO.										
INST. SCALE										
TRANS. NO.	POS.							IMP. %		
RATIO		120:1	500:5		120:1	500:5				
REG. IN SERIES	1	127.0	1.76	-200	127.0	1.76	+235	11.6		210.4
	2	128.0	1.74	-200	128.0	1.74	+235	11.6		210.4
	3	128.0	1.73	-197	128.0	1.73	+230	11.5		198.4
	4	129.0	1.71	-197	128.8	1.71	+230	11.5		198.4
	5	128.8	1.69	-195	128.8	1.69	+227	11.3		192.4
	6	129.0	1.68	-193	128.8	1.68	+225	11.3		192.4
	7	129.5	1.67	-191	129.0	1.67	+223	11.2		192.4
	8	129.8	1.65	-190	129.5	1.65	+222	11.1		192.4
	9	130.0	1.63	-190	130	1.63	+221	11.0		186.4
	10	130.0	1.62	-187	129.8	1.62	+218	10.9		186.4
	11	129.5	1.60	-183	129.0	1.60	+214	10.8		186.4
	12	129.5	1.59	-182	129.5	1.59	+213	10.7		186.4
	13	129.5	1.58	-181	129.5	1.57	+212	10.6		186.4
	14	129.0	1.56	-179	129.0	1.56	+210	10.5		186.4
	15	129.5	1.55	-177	129.5	1.55	+208	10.5		186.4
	16	130.0	1.54	-176	130	1.53	+206	10.4		180.4
	17	130.0	1.52	-175	130	1.52	+205	10.3		180.4

FIGURE 11

RUN FOR Constant HOURS AT 131,000 VOLTS 60 CYCLES AND 176 AMPS. 60 CYCLES
CONNECTION FOR SUB:

TIME	LOAD						TEMPERATURES °C.								
									CORE		RADIATOR				HOT SPOT
INST. NO.	VOLTS	AMPS.	WATTS	VOLTS	AMPS.	WATTS	OCOS	ICLES	TOP	BOT.	TOP	BOT.	TOP OIL	HEATER ON TANK	
RATIO	120:1	500:5	X_2	120:1	500:5	X_2									
9:00				START WITH ALL RADIATOR VALVES CLOSED											
9:00	150	2.08	-233	150	2.08	+282	22	23	24	22	24	22	24	24	
10:00	150	2.08	-233	150	2.08	+282	23	23.5	38	25	26	22	45	44	
11:00	149	2.06	-232	149	2.06	+281	23.5	23.5	49	27	32	22	58	55	
12:00	148	2.05	-230	148	2.05	+279	23.5	23.5	59	33	38	23	70	68	
12:00				ALL RADIATOR VALVES OPENED											
1:00	147	2.04	-229	147	2.04	+278	24	24	63	45	62	42	73	72	
2:00	147	2.04	-229	147	2.04	+278	25	25	64	46	63	43	74	73	
3:00	147	2.04	-229	147	2.04	+278	25	25	64	46	63	43	74	73	
3:00				LOAD REDUCED TO 100% CURRENT IN WINDINGS											
4:00	127	1.76	-200	127	1.76	+237	26	26	63	45	62	42	73	72	
4:00				HEAT RUN SHUT DOWN - HEAT RESISTANCES TAKEN											

FIGURE 12

Between Time to S.D.	$H_1 - H_2$			Between Time to S.D.	$X_1 - X_2$				
60 Sec.	7.50	3.74		150	.617	32.5			
70 "	7.44	3.73		160	.606	32.1			
80 "	7.36	3.70		170	.602	31.8			
90 "	7.34	3.69		180	.60	31.7			

RATIO
POLARITY
CORE LOSS FROM AT CYCLES TRANSFORMER RATIO
IMPEDANCE FROM AT CYCLES TRANSFORMER RATIO
OIL TEST AT .5" GAP 33,000 VOLTS
REGULATING TESTED:
L. V. TO L. V. AND CORE 95,000 VOLTS FOR 60 SECONDS
L. V. TO H. V. AND CORE 34,000 VOLTS FOR 60 SECONDS
RUN AT 3.16 TIMES NORMAL VOLTAGE 200 CYCLES FOR 60 SECONDS (Single phase)

After this breaker has been closed the voltage is raised on the transformer by increasing the field of the generator with the manually-operated field rheostats in the control desk. Test was started when about 80 percent of full voltage was reached. Measurements made from the meters on the control desk, which are permanently connected to the potential and current transformer of the test unit, are shown in Figure 9.

The next test is to determine the load losses and impedance of the windings. For this test the lines from the test unit output bus are connected to the high voltage bushings of the transformer, and the low voltage bushings shorted. The current transformer ratio is set for 500:5. The calculated value of impedance is approximately 11 percent, therefore the voltage required will be about 14,500 volts. In order to get this voltage without overexciting the generator, the test unit is changed to delta-wye connection. This would rise to a maximum of 23,800 volts when the generator is fully excited. Ratio of the potential transformer, which has a maximum of 18,000 volts with 150 volts on the secondary, is maintained at 120:1. A process similar to that described in the no-load loss tests is followed except that the parameter of testing is current. As shown in Figure 10, the values given are values taken to give the load losses.

New heat run method saves time

After the impedance test has been made the same connections may be used for the short circuit heat run. The total maximum losses, load loses on the position giving maximum loss plus the no-load loss, are calculated and the tap position for this maximum noted. In preparation for heat run a thermocouple or thermometer must be inserted into the top of the transformer in a position over the outlet of the cooling ducts from the coils so as to measure the maximum top oil temperature. Permanent temperature measuring devices, thermal relays,

and hot spot indicators must be connected so as to be checked during the heat run.

The transformer is energized in the same manner as for the impedance test except that the current is adjusted to a value where the total maximum watts as calculated are measured by the wattmeters. This value of watts is held until a constant oil temperature is reached. All radiator valves are closed until approximately 50 degrees oil rise is reached, the valves are then opened and oil temperature allowed to become constant, see Figure 11. Thus, the time required to reach the constant condition can be reduced to about one-third of normal.

The method of closing radiator valves, or leaving water cooling off on water-cooled transformers, is preferred over extra overloading since no excessively high hot spot temperatures are created in the winding. The ambient temperature is taken by having a jar with oil in it placed near the transformer where it will be subject to similar room temperature changes.

When the oil temperature has reached a constant value, the current in the windings is reduced to normal current on that connection and the current is held for one hour. At the end of this time the load is removed and resistance of the windings measured immediately.

Values of volts and amperes measured to determine the hot resistance of the transformer are shown in Figure 12.

Tests grouped for convenience

If impulse tests are to be made the transformer is moved to a position where it may be connected to the surge generator and tested. Low frequency voltage tests may be made following impulse testing.

The applied insulation test to ground for the low voltage winding is 34,000 volts. The testing unit is set for a single phase connection with high voltage and low voltage of two transformers in parallel. The testing transformer connections are made for 2,300 low voltage and 55,000 volts high voltage. This is applied by connecting the low voltage bushings of the transformer being tested together and to one testing bus. The other bus is connected to the case of the transformer and grounded. The potential transformer ratio selector is set for 60,000 to 150 volts.

The power is supplied from the same generator used for no-load and load loss tests. The voltage is raised to 34,000 volts for one minute and reduced gradually to normal voltage before the breaker is opened.

The high voltage winding applied voltage test to ground or neutral test for this transformer was 95 kv. One step of the 500,000-volt cascade test set is used for this voltage.

The power is supplied from the same 2,400-volt generator through interlocked air disconnect switches to the input of the high potential test set. A remotely-controlled oil circuit breaker is supplied on this input to protect the set and permit instantaneous opening of the circuit when sphere gap flashovers are used for calibration of the set, or in case of breakdown of the transformer under test. The controls for this breaker are located on the control desk, see Figure 3. The test unit is not energized for this test.

The measuring potential is supplied from a special potential transformer located at the input of the high potential test set. The secondary of this potential transformer is permanently wired to a particular voltmeter on the control desk which is used for this test exclusively. The high voltage line and neutral bushings are connected together and a 500-mm sphere gap is used in parallel with the winding to ground. All are connected to the high voltage bushing of the high potential test set.

The sphere gap is set for 50 mm. The disconnects are closed and the voltage raised until the sphere gap flashes over. The input voltage to the test set is read at the value for gap flashover. The sphere gap is flashed over three times and the average of the three meter readings taken. The sphere gap is opened to 70 mm but left in the circuit for protection. Voltage is raised to the average value previously taken and held for one minute.

Modernized testing is flexible

A full 275-kv applied test cannot be made on the high voltage winding because of reduced insulation at the neutral end of the winding. Instead, the induced voltage test is increased, from twice normal, to give 275 kv from each line bushing to ground. Provision is made during construction for opening the delta connection on the low voltage winding so that this test can be made single phase. In order to make it, approximately 45,000 volts must be applied across the low voltage winding. Since this is more than the applied voltage test on the low voltage winding, voltage to ground must be kept under 34,000 volts. This is accomplished by using the single-phase connection of the test transformers in series, and the low voltage windings of these two test transformers in parallel. The midpoint between the two high voltage windings is grounded.

Transformers are connected 2,400 to 27,500 volts. Potential transformer connection is made across one transformer to ground and set for 60,000:150 volts. The 200-cycle, 2,400-volt testing generator is connected through its set of air disconnect switches to the input of the test unit. The ouput leads from this single-phase connection on the test unit are connected to one phase of the transformer under test.

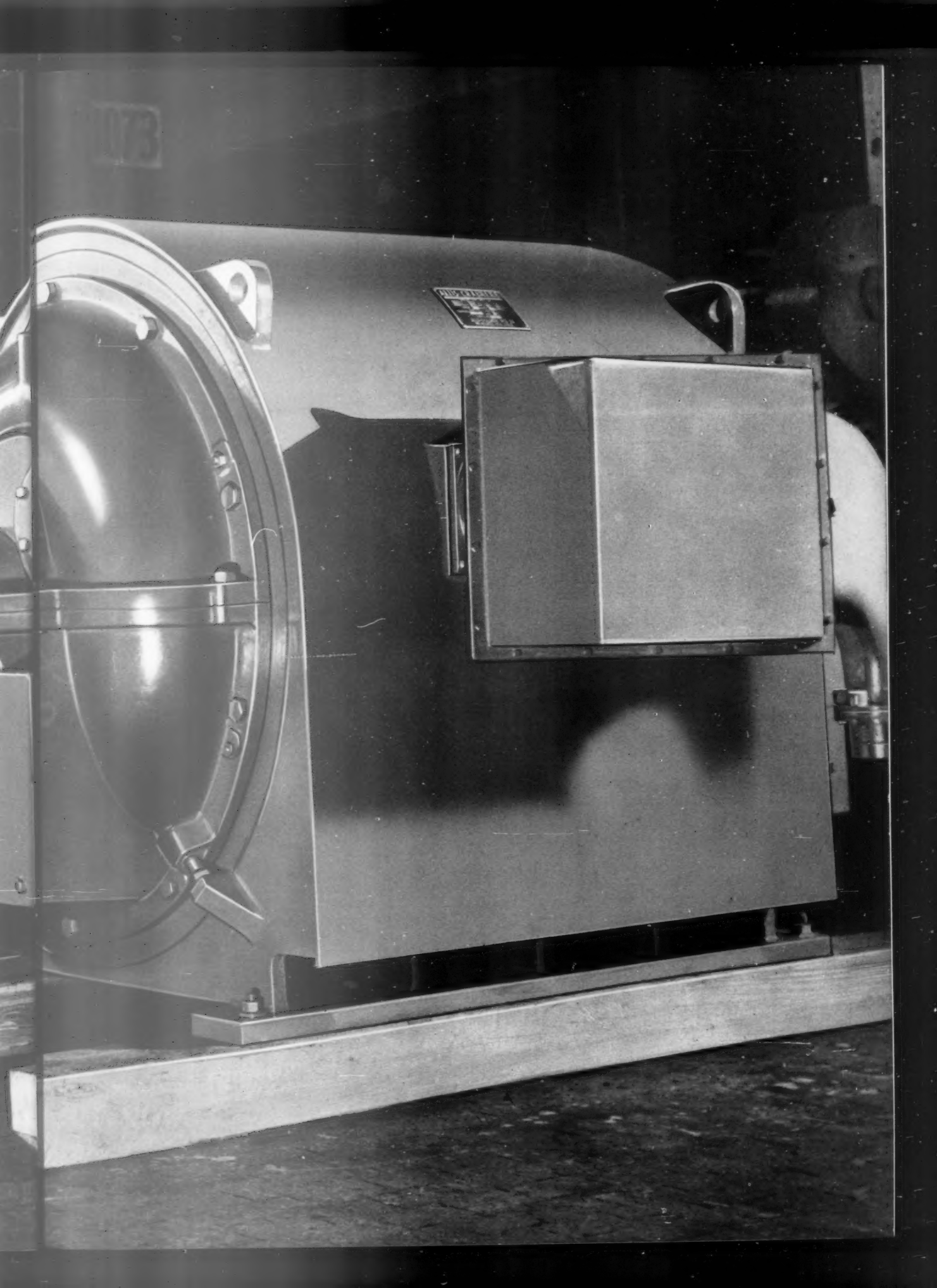
Field rheostats in the control desk can be switched to the field current of any of the generators used for test. The 500 mm sphere is connected to the line bushing of the high voltage winding of the same phase and the neutral bushing grounded. The sphere gap is set for 161 mm and the voltage is raised until the sphere gap flashes over. This is repeated to get three flashover points to average after which the gap is then opened to 201mm. The average voltage measured is held for 36 seconds. The same procedure is repeated for each phase.

The transformer can now be approved for shipment since it has met its loss, impedance, and heating guarantees and passed ratio and voltage tests showing that it is fit for service.

It will be noted that only the connecting required during the whole testing is to connect the transformer to the test unit, surge generator, and high potential test set. All other connections are made by air disconnects, motor-operated selector switches, or control switches on the control desk.

Modernized test facilities achieved the desired reduction in transformer production time and have simplified testing procedure. Older schemes, which provided generator connections to the test floor and used portable potential and current transformers, required the test operator to spend approximately 90 percent of his time in making connections and only about 10 percent of his time actually making tests. By standardizing equipment and test connections so that all connections, except those from the test buses to the transformer, can be made by motor or hand-operated switches, the proportions of set-up to operating time have been reduced to approximately 40 percent connecting and 60 percent testing time.

LARGEST 3,600-RPM MOTORS ever built for boiler feed pump service are being readied for shipment to a Midwest utility. Rated 3,500 hp, units are the largest two-pole squirrel-cage induction motors built to date and will drive the world's largest boiler feed pumps. This powerhouse project, when completed, will use five of these motors.



Phasing Out

SWITCHGEAR CONNECTIONS

by **ROBERT E. BURLINGAME**
Electrical Design Engineer
J. F. Pritchard and Company
Kansas City, Missouri

Proper phasing out procedure is essential to safety of personnel and switchgear.

CONNECTION OF A THREE-PHASE incoming power circuit or a three-phase generator to a switchgear unit is not merely a matter of establishing cable connections between the phases of the circuit or machine and three primary terminals of the switchgear unit. Before final electrical cable connections between a generator, or any other electrical power source, and switchgear terminals are made, and before closing a circuit breaker to connect a source to the bus, reliable methods of determining proper connections should be employed so that the phase sequence of the potentials delivered from the power source to the switchgear terminals and bus will be correct.

Phase sequence, also referred to as phase rotation, is the order in which positive voltage peaks occur on respective individually identified electrical conductors energized by a polyphase source.

Individual phase busbars of buses in modern three-phase switchgear are identified by the numerals 1, 2, and 3 to indicate the sequence in which the positive voltage peaks occur on the respective busbars when one or more generators, or other sources of three-phase power, have been correctly connected to the switchgear. Terminal blocks for secondary circuits of potential transformers and current transformers are also marked with the numerals 1, 2, and 3 to indicate the sequence in which the respective phase voltages and currents reach positive peaks in the secondary circuits of the instrument transformers. These numerals also indicate the phase relations between the high voltage circuit and the secondary circuits of the instrument transformers.

The same numerals, 1, 2, and 3, are also used in switchgear arrangement drawings to show the physical locations of the respective phases of the terminals for incoming and outgoing primary circuits. In switchgear wiring diagrams, the numerals 1, 2, and 3 are used to identify the phase wires of all instrument transformer secondary circuits throughout their connections to switchboard devices such as instruments, meters, relays, and generator voltage regulators. Although many of these devices will operate properly if the phase sequence of voltages and currents delivered to them is reversed, others will function incorrectly under such conditions.

As an example, a generator voltage regulator for a generator operated in parallel with one or more other generators will not function properly if the phase sequence established in the switchgear is reversed relative to the intended phase sequence on which the switchgear manufacturer's wiring was based. In such a case the regulator's cross-current compensating feature, which normally stabilizes the regulator and automatically prevents cross currents between generators, will have an opposite effect and create dangerously high cross currents between the generators. Other switchboard devices, such as certain instruments and relays, will not function properly if the phase sequence is reversed.

Phase out, then operate

The three main terminals of a three-phase generator are marked T1, T2, and T3, and when three additional terminals are provided to enable making the neutral connection between the windings of the generator outside of the generator, they are marked T4, T5, and T6. The six terminals are so marked that one-phase winding is connected between terminals T1 and T4, another between terminals T2 and T5 and the third one between terminals T3 and T6. The terminal markings T1, T2, and T3 do not necessarily indicate the phase sequence at the generator terminals. In accordance with standard rules the phase sequence at the generator terminals may be either T1-T2-T3 or T3-T2-T1, depending upon the direction of rotation of the generator and the physical location of the terminals on the machine.

Although the terminal locations identified by the numbers, and the phase sequence in terms of terminal numbers are shown on the generator manufacturer's drawings, it is highly advisable, and generator manufacturers recommend, that phasing-out tests be correctly and carefully carried out before putting a generator on the line for the first time. In view of the serious consequences which could result from errors it is certainly wise to perform the phasing-out tests properly.

An old method of checking the phase relations between a generator and a live bus consists of temporarily connecting several spare potential transformers of suitable ratio and three lamps as indicated in Figure 1 or Figure 2. In this method the generator is brought to approximately rated voltage and frequency and the actions of the three lamps are observed. Since the generator frequency will not match the bus frequency exactly, each of the lamps will vary periodically between full brilliancy and complete darkness.

If all three lamps go through their cycles of brightness and darkness in unison the generator phase sequence as delivered to the switchgear matches the phase sequence on the bus. If the three lamps do not go through their cycles of brightness

and darkness in unison, the generator phase sequence as delivered to the switchgear is reversed relative to the phase sequence on the bus and two of the three generator leads must be interchanged.

This method not only involves the hazards of temporary high voltage connections and the necessity for spare potential transformers, but furthermore has the disadvantage that it merely enables matching the generator phase sequence with the bus phase sequence without determining what actual phase sequence exists, or whether or not the actual phase sequence previously established on the bus is correct. Also, this method cannot be used to establish the proper phase sequence in switchgear when connecting the first generator or incoming line to the switchgear.

The method illustrated by Figure 2 can be carried out sometimes by using suitably located permanent potential transformers in the switchgear, thus eliminating hazardous temporary high voltage connections and the need for spare potential transformers, but the method still has a shortcoming in that it does not provide any indication of the actual phase sequence.

Test devices readily available

From the foregoing it should be apparent that methods which do not require spare potential transformers and hazardous temporary high voltage connections, which enable identifying and establishing of correct phase sequence and which require a minimum of compact and portable test equipment employing only low voltage temporary connections would be preferable to the method described in the preceding paragraphs. Methods having all of the advantages mentioned can be carried out through use of one simple, compact, and inexpensive test device known either as a phase sequence indicator or as a phase rotation indicator. Various forms of this device are commercially available.

One form includes a small reactor and two small incandescent lamps. The second consists of a small capacitor and two small neon lamps. A third form includes an electromagnetic assembly and a rotating disc. The first two forms each include internal multiplier resistors connected to terminals for use on voltages from 100 volts up to 440 or 550 volts. The rotating disc form is designed for operation on the same range of voltages without the need for multiplier resistors. In each of the first two forms connection to a three-phase potential source will cause one of the two lamps to burn brightly and the other to burn dimly or go out completely. Phase sequence 1-2-3 will cause one lamp to burn brightly and phase sequence 3-2-1 will cause the other lamp to burn brightly. In the rotating disc form of phase sequence indicator the disc will rotate in one direction to indicate a phase sequence of 1-2-3 and in the other direction to indicate a phase sequence of 3-2-1.

PHASING AND TESTING device is inserted into a standard circuit breaker switchgear to permit operator to make connections to both bus and line terminals. Device shown is not energized. The three top doors lead to bus phases, while the bottom doors lead to line circuit phases.

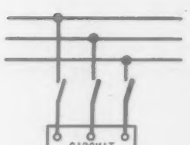
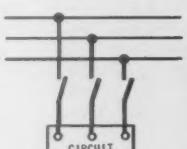
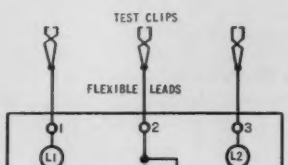


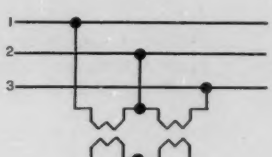
DIAGRAM SHOWS typical arrangement for phasing out tests using three spare potential transformers and three lamps. This arrangement gives no indication of phase sequence. **(Figure 1)**



THESE CONNECTIONS for phasing out switchgear use four spare potential transformers and three lamps. As in Figure 1, no indication of phase sequence is given. **(Figure 2)**



PHASE SEQUENCE INDICATOR of the lamp and reactor type connected as illustrated above is used on the secondary circuit of a three-phase set of potential transformers. **(Figure 3)**



PHASE SEQUENCE on a bus can be checked by using a phase sequence indicator connected to the secondary circuit of a set of two open delta-delta bus potential transformers. **(Figure 4)**

If a commercial phase sequence indicator is not at hand, a reliable phase sequence indicator can be made quickly and easily from readily available component parts. A connection diagram of such an indicator is shown in Figure 3. The two lamps are identical 110 to 120-volt incandescent lamps of three to ten watts capacity. The iron core reactor can be the potential coil of a watthour meter or relay, the primary winding of a bell ringing transformer (the secondary is left open circuited) or a filter reactor of the type used in small radio receivers. The lamp check switch can be any normally open push-button or small switch. This device is suited for use on the secondary circuits of potential transformers but may be adapted for use on 240 or 480 volts by connecting one or more additional lamps, or a suitable resistor, in series with each of the lamps shown in Figure 3.

The phase sequence indicator of Figure 3 is used by connecting its terminals 1, 2, and 3 to a three-phase source of potential, momentarily closing the lamp check switch to check both lamps and then observing the relative brilliancies of lamps L1 and L2 while the lamp check switch is open. One lamp will burn brightly and the other will burn dimly, or not at all. If L1 is the bright lamp, the phase sequence on terminals 1, 2, and 3 of the device is 1-2-3, and if L2 is the bright lamp the phase sequence is 3-2-1.

Testing methods vary

When preparing to energize switchgear by connection to it of the first generator or incoming line, the phase sequence indicator is connected to a set of bus potential transformers as indicated in Figure 4 or Figure 5. In Figure 5, about 200 volts will be applied to the phase sequence indicator so it will be necessary to use the 220-volt terminals of commercial lamp type indicators or to add lamps or resistors to the indicator of Figure 3, as previously described. The full line connections of Figure 5 are applicable when three potential transformers connected in wye-wye are used. Dotted line connections are applicable when two potential transformers connected in partial wye-wye are used.

After the phase sequence indicator has been connected, the bus is energized from the first generator, or incoming line. The phase sequence indicator is observed and, if the connections of the first power source to the switchgear are correct, the phase sequence will be indicated as 1-2-3. If the phase sequence is indicated as 3-2-1, two of the three cable connections must be interchanged somewhere between the terminals of the source and those of the switchgear. After the change in connections the phase sequence indicator should be observed again to confirm that the phase sequence has been corrected.

If the interchange of cable connections has been made within the zone of protection of differential relays, a corresponding change must be made in the connections to the secondaries of current transformers serving the differential relays. If the source circuit is provided with synchronizing facilities, the synchroscope should be checked by closing the synchronizing switch while the bus is energized from the source. Under these conditions the synchroscope pointer will position itself at the "12 o'clock" or "zero degrees" mark on the synchroscope dial, if the synchroscope is in operative condition and the synchronizing wiring has been correctly connected.

Generator-switchgear testing is complex

When phasing out connections between a generator and switchgear which is energized by a previously connected source, the procedure involves a few more steps. After the generator has been connected to the switchgear in accordance with the intended bus phase sequence indicated in the switchgear manufacturer's drawings and the generator phase sequence indicated in the generator manufacturer's drawings, and the neutral current transformer secondary circuits for the differential relays have been connected to the proper terminal block in the switchgear in accordance with the switchgear manufacturer's drawings, the following step-by-step phasing out procedure should be completely and rigidly carried out.

1. Mark the generator cables at the generator to indicate which ones of terminals T1, T2, and T3 each of the cables is connected to and then disconnect the generator cables from terminals T1, T2, and T3. Securely brace these cables apart so that they cannot become short-circuited or grounded. In some instances it may be more convenient to disconnect the neutral connections from generator terminals T4, T5, and T6 in

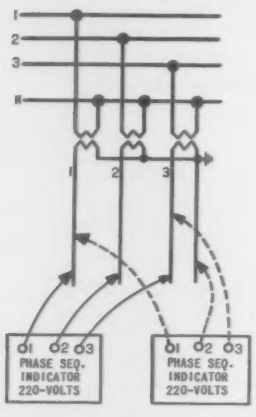
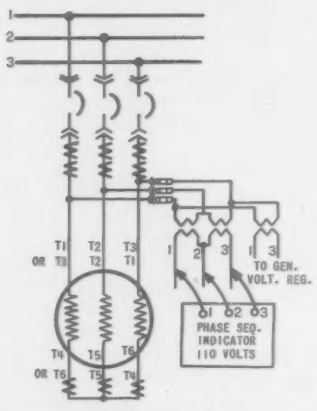


DIAGRAM ILLUSTRATES connections of a phase sequence indicator to wye-wye and partial wye-wye connected sets of bus potential transformers. **(Fig. 5)**



ARRANGEMENT SHOWN above is for connections of a phase sequence indicator to an open delta-delta set of generator potential transformers. **(Fig. 6)**

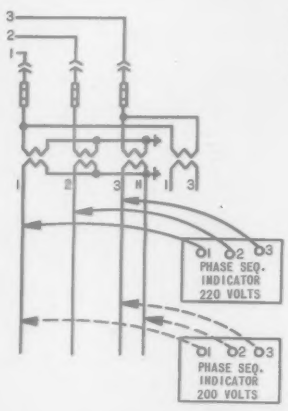
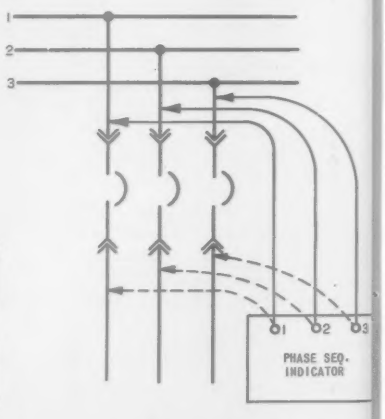


DIAGRAM SHOWS connection of a phase sequence indicator to a wye-wye or partial wye-wye set of generator potential transformers. **(Figure 7)**



CONNECTIONS OF PHASE sequenc indicator are for comparing phase s quences at the source and load sides a low voltage circuit breaker. **(Fig. 8**

place of disconnecting the cables from terminals T1, T2, and T3.

2. Connect a phase sequence indicator to the secondary terminals of the generator potential transformers, as indicated in Figure 6 or Figure 7. Figure 6 applies where two potential transformers are connected in open delta-delta and Figure 7 applies where potential transformers are connected wye-wye. In the latter case about 200 volts will be applied to the phase sequence indicator. Suitable provision must be made for this voltage, as previously explained. The full-line connections of Figure 7 are applicable when three potential transformers connected in wye-wye are used and the dotted line connections are applicable when two potential transformers connected in partial wye-wye are used. When the phase sequence indicator has once been connected it should be left connected until all tests have been completed.
3. Rack the circuit breaker into normal position and close the circuit breaker to put bus potential on the generator potential transformers and, hence, on the phase sequence indicator.
4. Observe the phase sequence indicator to determine the phase sequence on the bus. If the first generator or incoming line to be put on the bus was correctly phased out the phase sequence will be indicated as 1-2-3.
5. Close the synchronizing switch to check the synchroscope and the synchronizing wiring. If the synchroscope is in operative condition and the synchronizing wiring has been correctly connected, the synchroscope pointer will position itself at the "12 o'clock" or "zero degrees" mark on the synchroscope dial and also the synchronizing lamps will be dark. If the synchroscope does not indicate properly, it should be repaired or the synchronizing wiring corrected before proceeding further. The synchronizing switch should be left on for only relatively short periods and should be turned off when the synchroscope has been checked satisfactorily.
6. Open the generator main circuit breaker and lower the same to disconnected position.
7. Connect the generator cables to generator terminals T1, T2, and T3 in the same positions they occupied before they were disconnected in step 1.
8. Start the generator and bring it up to approximately its rated voltage and speed.
9. Observe the phase sequence indicator to determine whether or not the phase sequence when energized from the generator is the same as the phase sequence when energized from the bus, as observed in step 4. If the phase sequence is the same, the generator is properly connected to the switchgear and ready to be synchronized in on the bus. If the phase sequence is different than observed in step 4, the generator is incorrectly connected and the procedure outlined in step 10 and step 11 must be carried out.
10. If the phase sequence observed in step 9 is reversed relative to the phase sequence observed in step 4, shut down the generator and interchange the generator cables connected to any two of the generator terminals T1, T2, and T3. Then repeat step 8 and step 9 to confirm that the phase sequence at the switchgear terminals has been corrected.
11. Interchange the secondary wiring of the two of the neutral current transformers which are connected in phases corresponding to the generator cables which were interchanged in step 10. For example, if the main cables on generator terminals T1 and T2 were interchanged, the secondary wires on current transformers associated with generator terminals T4 and T5 must be interchanged.
12. After steps 1 to 9, inclusive, and steps 10 and 11 have been completed, the phase sequence indicator may be disconnected and the generator circuit breaker may be racked into normal position and synchronized in on the bus in accordance with standard operating procedure.

In phasing out 220, 440, or 550-volt equipment the same step-by-step procedure may be used if potential transformers are included in the switchgear. If potential transformers are not included, the phase sequence indicator may be used as indicated in Figure 8.

Indicator shows phase sequence

In using the method indicated in Figure 8 the phase sequence indicator is first connected to the bus terminals of the circuit breaker, as indicated in full lines, to determine the phase sequence on the bus. Then the phase sequence indicator leads are shifted to corresponding generator terminals of the circuit breaker, as indicated in dotted lines, and the generator is brought up to approximately rated voltage and speed for the purpose of determining whether or not the generator phase sequence as it appears at the circuit breaker terminals matches the phase sequence on the bus. If it does not, steps 10 and 11 of the foregoing step-by-step procedure must be carried out.

To check the synchroscope and synchronizing wiring in low voltage installations disconnect the generator cables from either the switchgear terminals or the generator terminals, close the circuit breaker and the synchronizing switch and note whether or not the synchroscope pointer positions itself at the "12 o'clock" or "zero degrees" mark on the synchroscope dial. When the generator cables are disconnected from the generator terminals, the cables must be braced apart so that they cannot become short-circuited or grounded.

In both cases care must be taken to mark the cables so that they may be reconnected to the same respective terminals from which they were removed. When the synchroscope has been checked and found to be in operative condition and properly connected, open the synchronizing switch, open the circuit breaker and reconnect the cables to the same respective switchgear or generator terminals from which they were disconnected.

After the phase sequence of the generator and the bus, as they appear at corresponding terminals of the generator circuit breaker, have been found to match and the synchroscope and synchronizing connections have been found to be correct the generator circuit breaker may be synchronized in on the bus in accordance with standard operating practice.

These methods of establishing correct connections between electrical apparatus and switchgear will be found advantageous over other methods from the standpoints of accuracy and reliability of results, need for a minimum of simple test equipment, and the minimizing of hazards to both men and apparatus.

IS MORE INERTIA THE ANSWER?

by G. BYBERG and V. J. EGAN
Motor-Generator Section
Allis-Chalmers Mfg. Co.
Milwaukee, Wis.

The question of adding inertia to hydraulic turbine synchronous generators is reviewed in the light of modern high speed switching.

THE SPEED REGULATION requirements of hydraulic turbines driving synchronous generators normally calls for a flywheel effect in the rotating element of the generator. This effect is a function of the permissible speed regulation, horsepower rating, and speed. It is not the intention to go into the theory of hydraulic turbines and governors here, nor to examine the methods by which the turbine builder calculates flywheel effect requirements. For discussions on that subject the reader is referred to literature expressly devoted to that subject.*

Rather the purpose is to outline the different factors entering into generator rotational inertia and to consider how this flywheel effect requires departures from normal generator construction.

Simple equations determine inertia

If generator rotors were designed only for the purpose of obtaining the necessary magnetic circuit in the spider rim and poles, utilizing the most suitable construction for the particular speed (and overspeed requirements), the average normal flywheel effect for standard 0.8 pf generators could be very closely approximated by the equation:

$$\text{Rotor } Wk^2 = \frac{Kva^{1.25} \times K}{\left(\frac{Rpm}{1000}\right)^2} \qquad (1)$$

Where K = 0.69 for 13,800 volts
0.64 for 6,900 volts
0.60 for 2,500 volts and below.

For example, for a 12,500 kva 720 rpm 13,800 volts generator the mean or average value of Wk^2 would be

$$\frac{12{,}500^{1.25} \times 0.69}{(720/1000)^2} = 176{,}000.$$

* Copies of "Hydraulic Turbine Handbook" by Arnold Pfau can be obtained by writing to the Electrical Review.

The average or mean values are used as the most practical for this purpose since the rate of change is not a perfectly smooth progression. For a given number of poles, the rotor diameter will change in steps rather than in a continuous progression with several ratings being built on each diameter. Thus each diameter rotor has its own set of Wk^2 values.

Inertia constant

ASA Standards C-42- 1941, American Standard Definitions of Electrical Terms, defines the inertia constant as the energy stored in the rotor of a machine when operating at rated speed expressed in kilowatt-seconds per kva rating of the machine.

$$\text{The inertia constant is } H = \frac{0.231 \times Wk^2 \times n^2 \times 10^{-6}}{Kva} \qquad (2)$$

Where Wk^2 = moment of inertia in lb-ft.^{2}.
n = speed in rpm.

Combining equations (1) and (2) and transposing, we find that the inertia constant of generators with "normal" rotor construction is

$$H = \frac{0.231 \times Kva^{1.25} \times K}{Kva} \qquad (3)$$

Hence, H varies with kva, voltage and power factor, but for any given kva, voltage and power factor it is practically constant, regardless of speed.

Hydraulic regulating constant varies

The hydraulic regulating constant is a value usually specified by the turbine builder. It varies with horsepower, speed and hydraulic conditions and is determined by the equation:

$$\text{Hydraulic Constant} = \frac{800{,}000 \times T}{R} \qquad (4)$$

Where T = time in seconds required for gate closing. This will usually be on the order of two seconds for small units and decreasing to one and a half seconds for intermediate sizes and even one second for large units. This, however, depends on hydraulic conditions, such as intake (whether open flume, closed penstock, etc.).

R = Percent regulation expressed as a decimal may be 0.30 to 0.40.

The regulating constant may thus vary over wide limits, from four million, which is usually a minimum value, to ten million or more. The flywheel effect required is then determined by the equation:

$$Wk^2 = \frac{\text{Hydraulic Constant} \times Hp}{Rpm^2} \qquad (5)$$

Where Hp = turbine horsepower.

Overspeed requirements pose problem

In the foregoing, the "normal" flywheel effect is predicated on an established industry practice that fixes the overspeed of standard hydraulic turbine-driven synchronous generators at

INERTIA CONSTANT "H"

185 percent of normal speed for rated speeds of 360 rpm and above and all ratings over 50,000 kva, and at 200 percent of rated speed for lower speeds up to 50,000 kva. This was derived from the fact that the impulse-type turbine, which has a runaway speed of approximately 185 percent of normal, was generally used for high head, high speed units. The reaction type turbine, having a runaway speed of 165 percent to 200 percent, was generally used for medium and low head, low speed units.

Another deviation from standard practice comes up in considering the Kaplan adjustable-blade type turbine which may have theoretical runaway speeds as high as 270 percent of rated speed. But as this type is confined to the low speed field, the effect is not as difficult to meet as in the high speed class.

However, progress in the art of turbine design has tended to push the reaction type into ever higher heads and speeds, particularly for large capacity units. This introduces serious problems in regard to both the flywheel effect and the overspeed in the generator.

It will be obvious that, in the case of a large high speed generator which is already designed for a peripheral speed corresponding to minimum conservative factors of safety at rated overspeed, any further requirement that the rotor withstand higher overspeeds will necessitate a reduction in the rotor diameter. But this reduction in diameter is accompanied by a reduction in flywheel effect which is very nearly proportional to the increase in overspeed. For example, if such a high speed generator is required to withstand a top speed of 202 percent of normal, as against a normal overspeed of 185 percent of normal, the increase in overspeed is 20 percent and the reduction in rotor flywheel is very nearly the same percentage.

In a properly designed generator, a reduction in rotor diameter is accompanied by a reduction in the output factor (kva per unit dimension), so that the active rotor length will increase in a greater proportion than the reduction in rotor diameter. Hence the length may become so great that the distance between bearing centers not only precludes adding further Wk^2 in the form of a flywheel, but may even bring about a problem of mechanical stability.

Short-circuit ratio affects design

Generators of standard design have a short-circuit ratio of 1.0 for 0.8 pf. For the larger ratings the normal SCR is 1.1 for 0.8 pf. For the larger ratings the normal SCR is 1.1 for 0.9 pf and 1.25 for 1.0 pf.

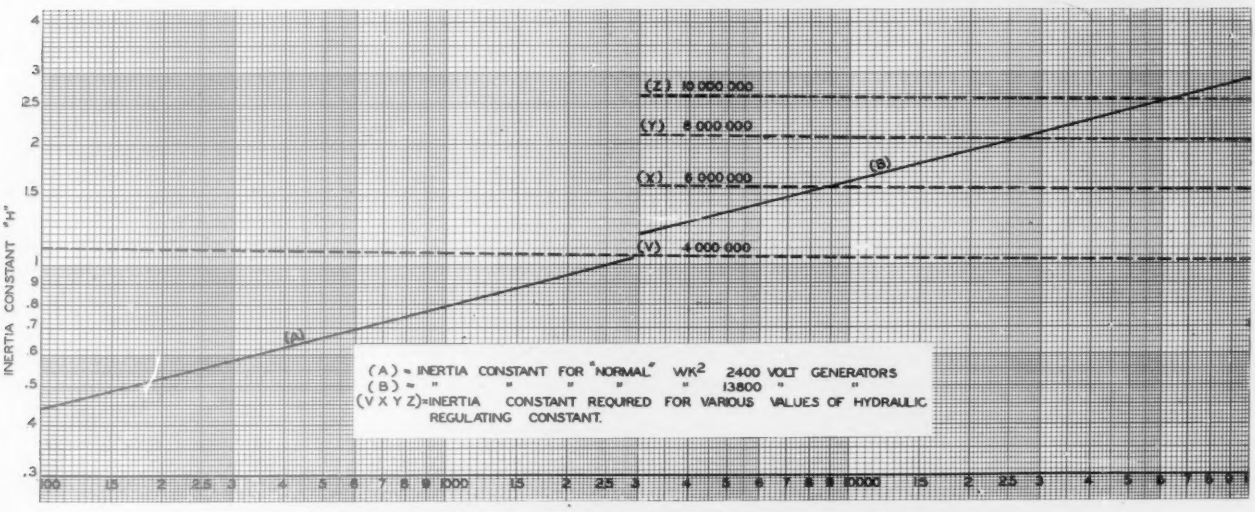
For a large percentage of installations, and particularly where some form of high speed excitation system is used, these standard short-circuit ratios are usually sufficient. However, there are a considerable number of special cases where the requirements of higher than normal line-charging capacity or lower than normal direct-axis transient reactance will necessitate higher than normal values of SCR. An example of this are some of the Hoover dam generators which have a short-circuit ratio of more than double normal (2.7 at 1.0 pf).

If it is assumed that the physical dimensions of the generator increases as the square root of the SCR (an assumption which, although not very accurate, is close enough for this purpose), then the normal inherent flywheel effect will be approximately that of the equivalent rating. For example, a 25,000-kva, 0.8-pf generator with an SCR of 1.5 would have a normal flywheel effect approximately equal to the equivalent normal 1.0 SCR machine of $25{,}000 \times \sqrt{1.5}$ or 30,600 kva.

Building in high inertia

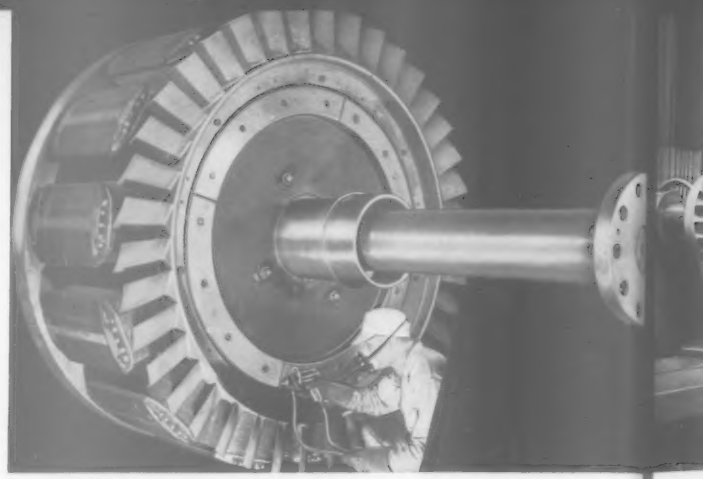
The data in Figure 1 is based on best modern hydraulic generator practice and represents the relation of the inertia constant "H" for average normal values of rotor Wk^2 to that required for various values of hydraulic regulating constant. Line A is for the smaller 2,400-volt generators and line B for the larger 13,800-volt machines. While the values of normal Wk^2 shown do represent average conditions quite closely, they of course will be subject to some variations and should not be considered as determined by any standardization.

It will be seen that in the case of 2,400-volt generators up to 3,000 kva, the normal rotor Wk^2 will not meet the inertia constant requirement corresponding to a minimum hydraulic regulating constant of 4,000,000. Note that the smaller ratings have the greater deficiencies. Conversely, in the larger 13,800-volt generators, the inherent flywheel effect increases at


INERTIA CONSTANT "H"
(Z) 10 000 000
(Y) 8 000 000
(X) 6 000 000
(V) 4 000 000
(A)
(B)
(A) = INERTIA CONSTANT FOR "NORMAL" WK² 2400 VOLT GENERATORS
(B) = " " " " " " 13800 " "
(V X Y Z)=INERTIA CONSTANT REQUIRED FOR VARIOUS VALUES OF HYDRAULIC REGULATING CONSTANT.

RELATION of inertia constant "H" for normal values of rotor Wk^2 to that required for various values of hydraulic regulating constant is shown in curves. **(Figure 1)**

ROTOR WITH SOLID SPIDER built up of stacked heavy steel plates. Generator is rated 6,600 v., 6250 kva, 514 rpm. **(Figure 2)**



ROTOR WITH SOLID SPIDER and plate steel flywheel for 6,250 kva, 514 rpm vertical generator. Note brake ring on spider. **(Figure 3)**

such a rate that 10,000-kva units meet a regulating constant of 6,000,000 or more.

Obviously, then, any inertia constant requirement which is above the line representing the inertia constant for normal Wk^2 must be met by special means. This may be by a flywheel furnished by the turbine builder in the case of small high speed units. But in all other cases it must be furnished through some form of mechanical modification of the generator rotating element. The methods by which such modifications are achieved is dependent upon a great many things, such as the kva, voltage, rated speed and overspeed, physical dimensions, etc.

Because of the wide variations in the inherent characteristics required in the generator and in the turbine for different operating conditions, it is impossible to set up any definite lines of demarcation among the various types of rotating element construction. The following general classes, however, indicate the more usual categories.

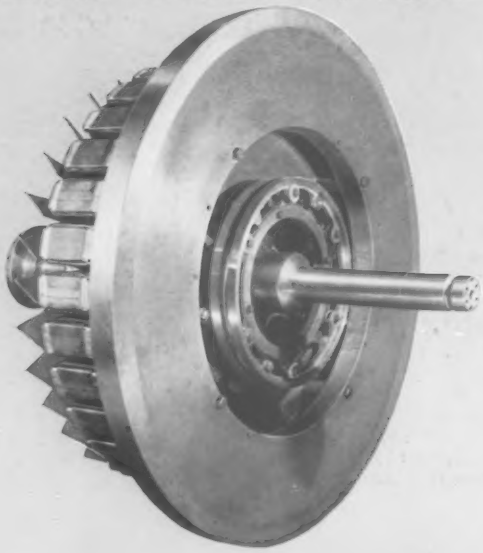
1. Solid spider construction

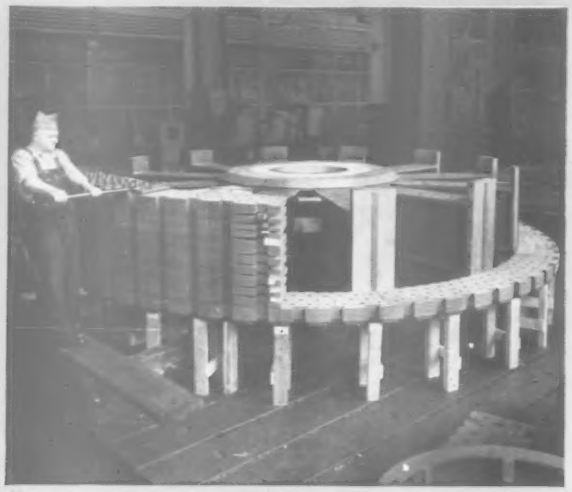
Solid spiders are generally used for all generators having speeds of 500 rpm and higher and in some cases for intermediate ratings for speeds as low as 300 rpm. These spiders may utilize either laminated or boiler plate construction.

With the spider solid, i.e., without axial openings, and the coil stickout for high speed machines proportionately long, the most practical way of obtaining the additional Wk^2 is by means of a separate plate steel flywheel. Small additional WK^2 is most readily obtained by lengthening the spider since it is simple, economical and does not increase overall length.

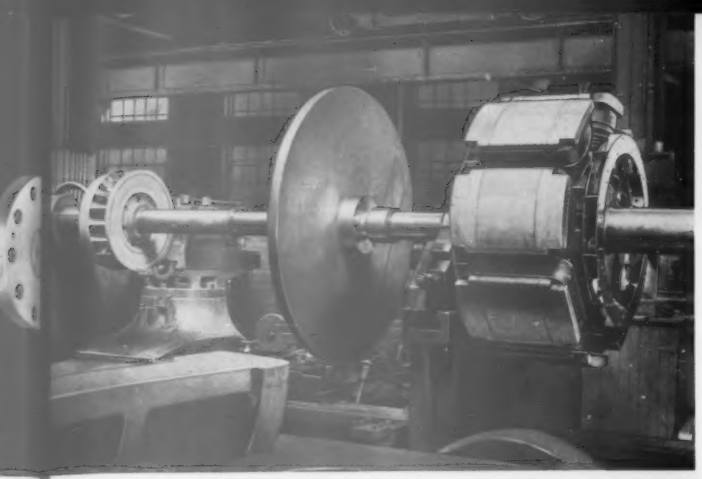
For vertical generators, the stator yoke construction and the ventilating arrangement usually can be modified so that the flywheel can be accommodated within the machine and mounted directly on the shaft. For horizontal machines the flywheel arrangement will to some extent be dependent upon the generator rating and physical arrangement. With the smaller sizes the flywheel must, in most cases, be mounted between the generator and turbine coupling flanges. In the case of the larger pedestal bearing type units it may be necessary to couple a separate flywheel shaft to the generator shaft and introduce an extra bearing between generator and turbine, or in some cases it may be permissible to mount the wheel inside the outboard generator bearing pedestal. Figures 2,

ROTOR WITH BALLAST RING of plate steel supported from the spider rim is shown below. Unit is rated 625 kva, 225 rpm. **(Figure 6)**





TEST STACKING OF LAMINATED RIM (above) is standard procedure when completed rotor is too large or heavy for shipment. Pole pieces are inserted in dovetails around circumference. **(Figure 7)**



SOLID ROTOR WITH FLYWHEEL of plate steel mounted between turbine and generator rated 1,000 kva, 900 rpm. **(Figure 4)**

ROTOR WITH HEAVY ROLLED RIM for a 1,250 kva 112½ rpm generator. Rim is typical of maximum section that can be rolled. **(Figure 5)**

3, and 4 show various methods used to obtain the desired high flywheel effect.

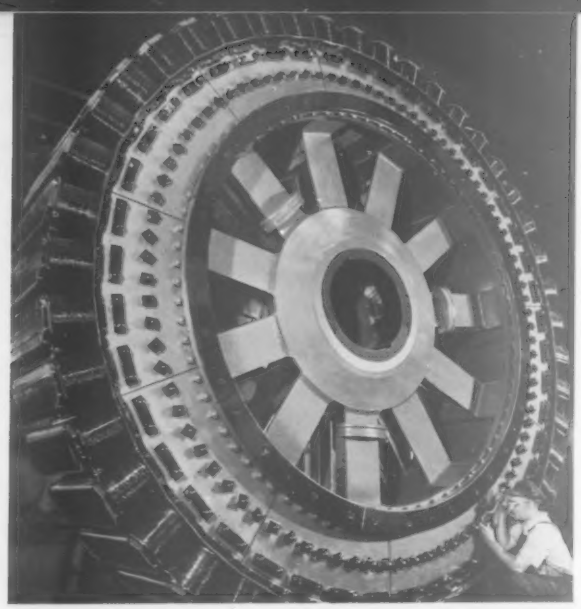
2. *Fabricated steel spiders*

Fabricated plate steel spiders built up from weldments and having a rolled steel rim are used for small and intermediate ratings in the intermediate and low speeds.

Wherever additional flywheel effect is required, the rim is made sufficiently heavy to provide it. Figure 5 shows a spider of this type for a 1,250-kva 112½-rpm vertical generator which had a low enough peripheral rotor velocity so that bolted-on poles were used.

There are, however, many cases where it is either impossible or uneconomical to get the additional flywheel effect needed by simply using a heavy rim and in such cases a ballast ring or a flywheel must be added. The ballast ring is preferable since it is supported from the rim and interferes less with normal ventilation and other shaft mounted parts. An example of this is the rotor shown in Figure 6 for a 625-kva 225-rpm vertical generator.

LAMINATED RIM ROTOR for 33,000 kva, 225 rpm horizontal generator with half the poles being fitted in place. One of the largest horizontal generators in the U. S., it was recently installed in a West coast hydraulic plant. **(Figure 8)**



COMPLETE ROTOR with unusually deep laminated rim for a 16,667 kva, 164 rpm vertical generator is shown above. This type of construction is used where great rotating inertia is required. **(Figure 9)**

CONTRAST WITH HIGH INERTIA ROTOR at left is the spider construction above, built for a 22,500 hp, 180 rpm vertical synchronous motor. No flywheel effect is provided in this design. **(Figure 10)**

3. *Laminated spider construction*

In the case of large generators in the intermediate and lower speed range, requiring flywheel effect considerably above normal, the use of rolled steel rim may be, and of solid boiler plate type will be, out of the question. With rolled rims, a point is reached where either a slab of suitable proportions is unavailable or it will have a thickness that is difficult if not impossible to hot roll. The solid plate type becomes impractical because of its inherent uneconomical use of the steel plate and because the rotor weight becomes disproportionate calling for extreme thrust bearing and crane capacities.

These limitations have led to the use of laminated rims, which permit the attaining of the highest flywheel effect commensurate with minimum weight. The rim is built up of accurately die-punched high tensile strength sheet steel of approximate one-eighth inch thickness. The laminations are staggered in stacking and held between heavy steel end plates by means of alloy steel through bolts having locked nuts on both ends.

This construction has two distinct advantages: (1) The rim may be made any reasonable depth; (2) It produces a uniform rim resulting in a minimum of balancing problems. Practically all of the larger intermediate and low speed generators installed in recent years have rotor spiders of this type. A number of typical ones are illustrated by Figures 7, 8, and 9.

Many factors affect system stability

Not only generator flywheel effect, but also generator and system reactance and fault-clearing time, as well as the rotating inertia of the load, are all important in determining system stability. There may be in some cases a tendency to overemphasize the benefits of a higher than normal flywheel effect, without giving due consideration to the restrictions it imposes on generator design. Since the problems become more serious on larger installations, careful thought should be given to the factors entering into the stability of any given system. Generator and system reactance and fault-clearing time should all be carefully investigated before any departure from normal flywheel effect is specified.

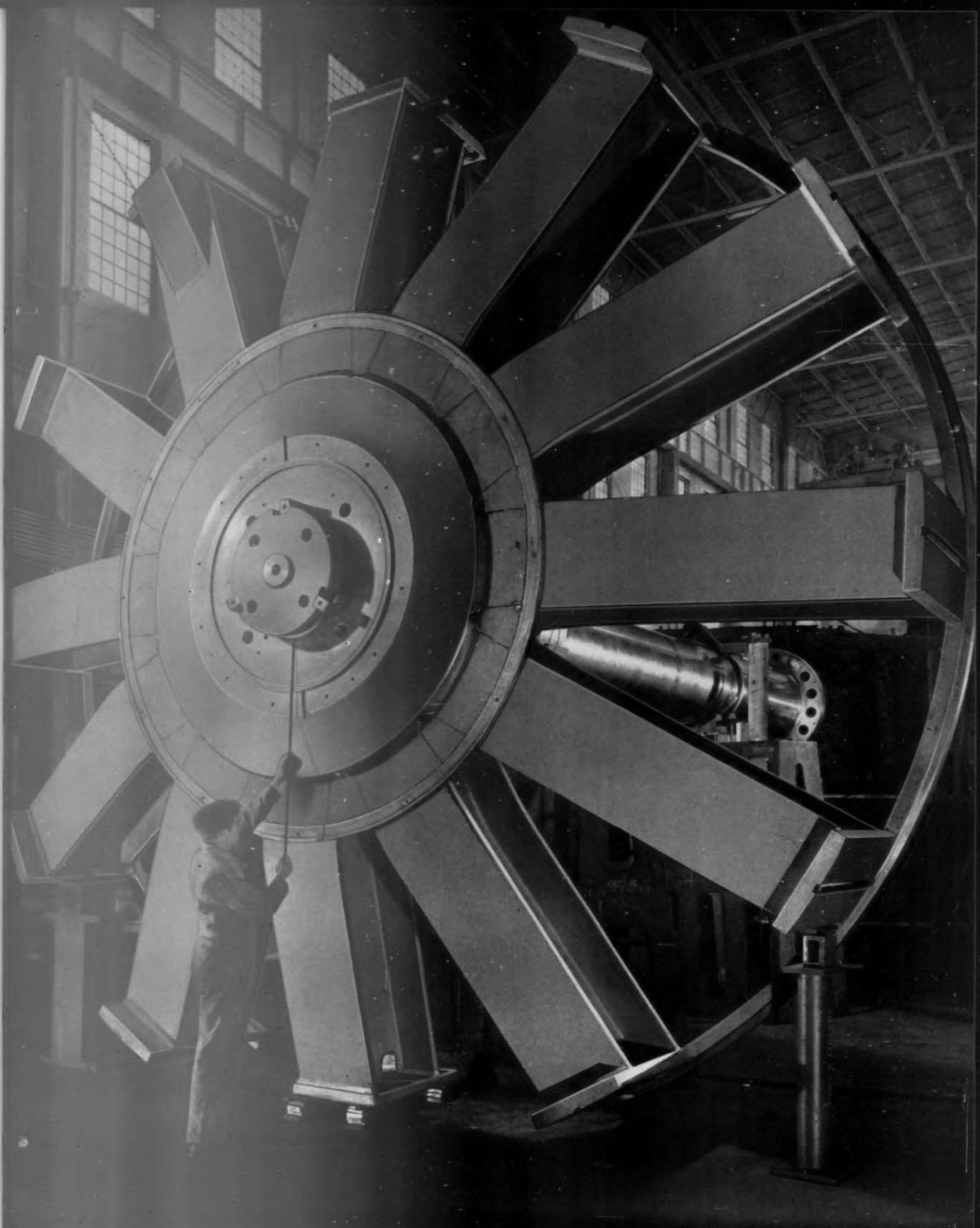
In analyzing the system during fault conditions, it will be found that, for the duration of a properly relayed fault, the turbine governors do not have time to act and adjust the turbine input for the change in load. Thus the ability of the generators to remain in step during this interval is entirely a function of the flywheel effect. However, in most stability studies, the flywheel effect of the generator unit alone is used to determine system stability. This obviously gives a pessimistic answer, since it disregards the flywheel effect of the rotating equipment in the load. In any thorough analysis, this factor must also be added to determine the true inertia constant of the system.

It should also be pointed out that with the increase in relay and breaker operating speeds, and the advent of high speed reclosing circuit breakers, the generator flywheel effect has assumed less and less importance in the stability picture.

Since the ability of two generators to remain in synchronism for a fixed fault-clearing time is a direct function of their flywheel effect, it can be seen that, for the hypothetical case of zero fault-clearing time, the flywheel effect would not be a factor. The few cycle interval required by modern relays and switching equipment approaches this hypothetical limit. Thus, in all but the most unusual cases, careful investigation may show that it is uneconomical to specify additional flywheel effect in the generator rotating element in excess of that required for turbine speed regulation. For the extreme case where a generator serves a system load alone, enough flywheel effect is required in the rotor to permit the governor to regulate the input to the turbine without undue speed change.

It has been customary practice on hydraulic turbine units to calculate the speed rise both for full load rejection and for rejection of partial loads. Speed rise on full load rejection is of no importance, since the generator is built to operate at the full runaway speed of the turbine. Where the full load is rejected the unit is disconnected from the system and there is then no requirement for maintaining a uniform speed.

It is generally impossible for the fractional load changes to approach a sizable percentage of the full load speed change unless the generator is cut off from the system and left with an isolated load. Even in this extreme case, it should be remembered that, because of the rotating inertia of the load, the speed regulation will be better than the calculated value based on the generator flywheel effect alone.



ROTOR SPIDER for a 22,500-kw, 28,000-kva, 13,800-volt vertical hydroelectric generator will be the tenth such unit to be installed at TVA's Wilson Dam. Generator is to be directly connected to Francis running hydraulic turbine rated 35,000 hp at 100 rpm under 92-foot head. When completed, station will have 18 hydraulic turbines in service. Partially finished rotor is example of design where no extra flywheel effect is needed.

NEW BLOOD For Old Switchgear

by **C. J. TEASLEY***
Switchgear Section
Allis-Chalmers Mfg. Co.
Milwaukee, Wis.

Replacement air breakers increase interrupting capacity without the need of replacing entire switching installation.

UTILITY AND PLANT engineers are faced with the seemingly constant problem of economically increasing substation and distribution system capacity to satisfy steadily rising industrial, commercial, and residential demand for electric power.

They have several alternatives at their disposal. Sometimes the installation of a complete substation unit to serve a new area may provide the answer; other times additional distribution circuits could be provided; transformer capacity could be increased; perhaps a new installation of metal-clad switchgear in existing stations may be the solution. But there are many instances where additions to existing facilities are either physically or economically out of the question, or both.

A good example of prohibitive circumstances is that of a substation housed in a perfectly good building supplying a load in excess of the originally planned ultimate capacity. As the load increased, new transformer capacity was added, and the buses were extended with additional feeder breakers. Perhaps additional transformers were installed, until the short circuit capacity on the bus was much greater than the interrupting capacity of the original breakers. With the building already full of equipment, it might be very costly to expand space to house additional equipment needed to serve the load or to replace the overall installation with adequate switchgear.

Another instance would be an industrial distribution center feeding a plant that had grown around it. With no space for additional feeder breakers or new switchgear, the old installation has to make the best of it and hope that no serious difficulty will arise.

These conditions constitute an ever-present hazard to personnel and equipment. The danger of long, costly shutdowns of vital services is another concern that has to be considered under such inadequate and strained circumstances.

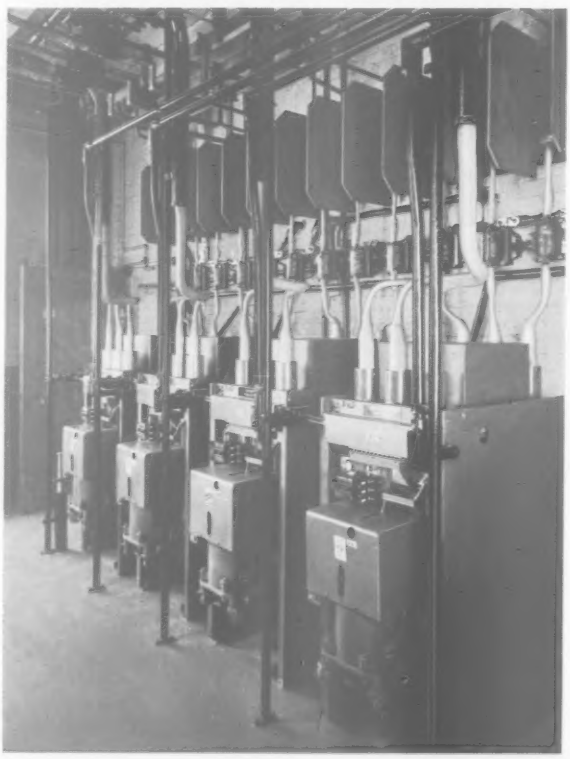
Replacement breakers boost capacity

Inadequate and crowded substations or distribution systems can be built up to meet sharply rising demands without resort to physically or economically prohibitive methods. The recently developed air magnetic draw-out circuit breaker replacement units, built in ratings up to 4.76 kv, with 50,000-kva up to and including 250,000-kva interrupting capacity, provides the equipment necessary for increasing capacity with a minimum of expense. Physical design and improved operating principles make utility and industrial distribution station modernization economically justifiable.

Because their overall dimensions are small, it is possible to fit replacement circuit breakers in place of older and obsolete low capacity oil breakers. Frame-mounted breakers require room around them to facilitate normal maintenance and space must be provided for dropping the tank. With replacement units, this arrangement is unnecessary since draw-out circuit breakers are mobile and can be removed to a convenient inspection and test location, if desired. Normal front aisle space, however, must be sufficient to draw circuit breakers out of the structure.

When existing frame-mounted breakers, shown in Figure 1, are replaced with air magnetic draw-out circuit breakers (Figure 2), existing bus work, current transformers, disconnect switches, and other equipment is salvaged. Cells can be left intact and pipe frame work left in place. The only change

REPLACEMENT SWITCHGEAR can be used to rehabilitate inadequate interrupting capacities without disturbing buses, disconnect switches, current transformers, and other apparatus. This 5-kv, 150-mva installation was accomplished without changing the station's physical layout.



* Mr. Teasley is now employed by the U. S. Government in the Hawaiian Islands.

that has to be made is in circuit breakers, thus minimizing installation expense. Where no additional space is available, this would be the only answer short of rebuilding the entire station. In many instances where additionally needed space is available for new switchgear, it becomes an economic problem of justifying the cost of a new switchgear installation in addition to scrapping existing equipment.

Replacement units integrate design principles and advantages of modern switchgear. For instance, the breaker with its control relays, primary fingers, and secondary (control) plugging device is mounted on wheels. This complete movable portion is identical to the one used in standard switchgear. The elevating mechanism which raises the breaker into operating position, primary studs, plugging and grounding devices are also standard switchgear components.

A plug jumper and a wall-mounted test box are provided with the accessories. The plug jumper is used for testing the breaker in the test position by completing the control connections while the primary connections are safely separated. This provides an easy means for testing the entire operating circuit. The test box can be located at a convenient working area remote from the switchgear for checking the operation of the breaker mechanism. Maintenance is easier in the open than in the narrow confines of a switch cell or framework, and routing checks at this location are more likely to spot possible sources of trouble than if the breaker were fixed in an awkward position.

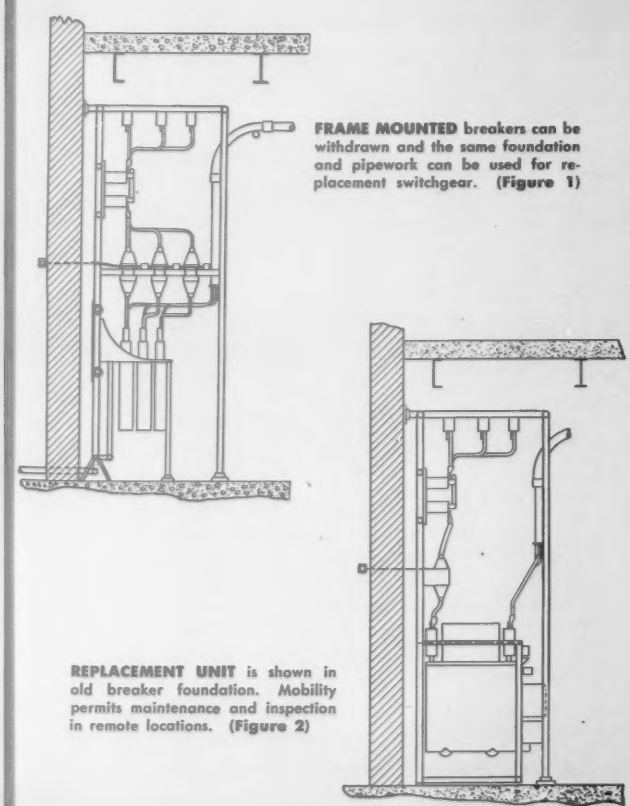
Fits a-c and d-c sources

The application of replacement units is generally limited to the minimum cost modernization of existing stations. Modernization becomes necessary when the available short circuit capacity of the system exceeds the breaker interrupting capacity. If an analysis of the system shows this to be true it may be good economics to replace the inadequate breakers before a severe fault results in excessive damages. It is also advisable to provide for easier maintenance both to save unnecessary labor and to encourage closer inspection.

An inspection of the unit outline will determine whether the replacement breaker will fit the available space. Dimensions of the 100,000-kva, the 150,000-kva and the 250,000-kva units are shown on Figure 3. The aisle space shown is necessary to withdraw the breaker from the unit.

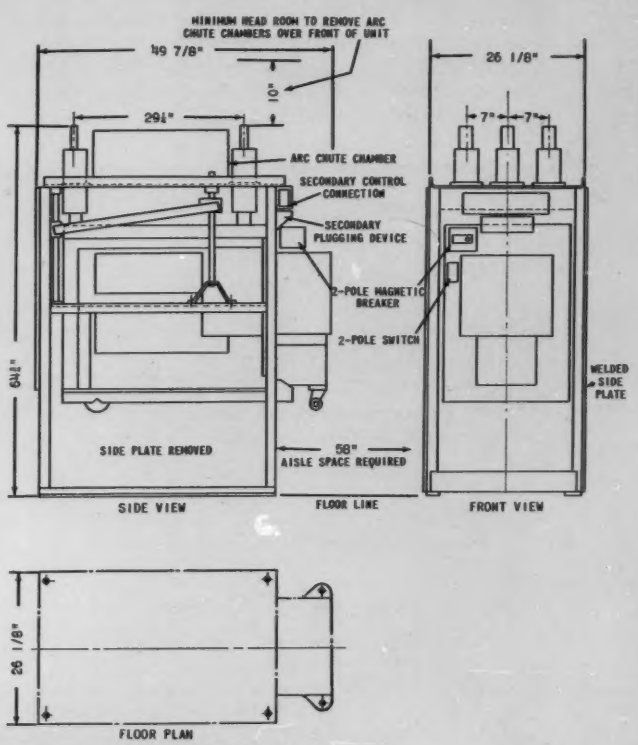
Air magnetic draw-out circuit breaker replacement units are available for all standard a-c and d-c control voltages, permitting use of the existing control source. The control circuits may be wired directly to the fixed position plugging device. A two-pole magnetic breaker and a two-pole enclosed switch can be wired into the control circuit as required for protection and sectionalizing. The standard schematic diagram is shown in Figure 4.

The control source should be able to furnish up to 100 amperes at 125v d-c or 240v d-c for closing these breakers. In most cases this requirement will be well within the capacity of the existing source. If battery supply is used, it will also



FRAME MOUNTED breakers can be withdrawn and the same foundation and pipework can be used for replacement switchgear. **(Figure 1)**

REPLACEMENT UNIT is shown in old breaker foundation. Mobility permits maintenance and inspection in remote locations. **(Figure 2)**



SKETCHES ILLUSTRATE major component parts and dimensions of replacement switchgear. Less than five feet of space is required to permit withdrawal of breaker from framework. **(Figure 3)**

take care of the trip requirements. If a-c trip is desired the breakers can be furnished with suitable trip coils.

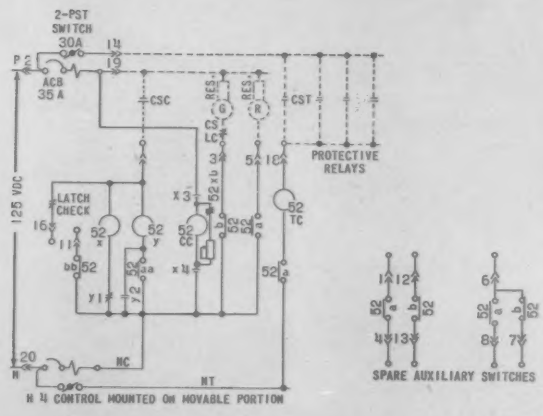
The test location selected should provide room for easy access to all sides of the breaker, with the test box conveniently mounted on the wall. The control source should be wired to this box. (When a-c series or reactor trip is required, an a-c shunt trip coil is supplied for manual tripping. Its supply is connected to the test box.) In most cases the existing relaying equipment connections and settings remain unchanged. The number of auxiliary switches available should be sufficient for all applications (Figure 4).

Range of uses widening

Modernization and expansion plans are the rule rather than the exception today. Many utilities and industrial plants need increased capacity to provide dependable service at all times but cannot fully justify new stations. Because the new replacement breaker units provide an intermediate, less expensive choice between depending on worn out, inadequate equipment and expensive replacement of entire stations, they promise to become an increasingly important consideration of all modernization and expansion plans. Replacement units should be considered whenever the problem of increasing loads is encountered.

There are also certain special applications of circuit breakers where air magnetic draw-out breaker replacement units would be an improvement over previously available equipment. Portable substations for utilities, mines, etc., or other installations where space is limited, can now be provided with the advantages of draw-out breaker construction where previously only frame-mounted breakers could be applied.

Underground installations where space limitations are critical can use draw-out equipment to advantage in avoiding maintenance in restricted space. The breakers can be withdrawn easily and taken to a shop for maintenance and inspection. Other applications will undoubtedly arise where standard metal-clad switchgear cannot be applied.



SCHEMATIC DIAGRAM of circuit breaker control shows typical control scheme of replacement circuit breaker. Usually, existing relays, connections and settings remain unchanged when new breakers are used. **(Figure 4)**

New Products

Redesigned Outdoor Switchgear Offers Greater Weather Protection, Safety and Space

Outdoor high voltage metal-clad switchgear has been redesigned to provide additional protection against weather, improved personnel safety and increased space for auxiliary equipment. The new design is adaptable to many more applications than older equipment because a wider variety of circuit arrangements is possible in a standard circuit breaker unit.

Space is available above the main bus compartment for 15-kv drawout potential transformers or a 10-kva drawout control transformer. A transfer bus and disconnect switch or lightning arresters can be mounted in this space, if desirable. Additional units are often unnecessary because adequate space is provided for auxiliary equipment greatly reducing space requirements and, consequently, foundation and installation costs.

Greater personnel safety is afforded by a full-length bolted-on steel barrier placed between the circuit breaker and instrument panel compartments. An oversize hinged instrument panel provides more space for instruments, relays and switches.

Welded-in steel plates form a sturdy floor for circuit breakers and protect equipment from rodents and other small animals. Overhanging eaves prevent driving rain and sleet from getting into the housing. Copper mesh filters behind louvres keep out dust, dirt and insects without hindering air circulation. Space heaters eliminate moisture condensation, a frequent cause of insulation failure.

New Distribution Transformers Are Self-Protected Against Any Fault Condition

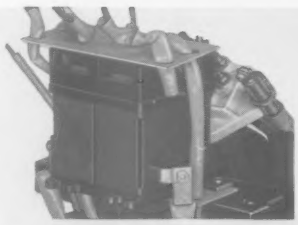
A new line of self-protected distribution transformers for urban and rural use is now available in ratings of 100-kva and smaller, in voltages of 14.4-kv and lower, single phase.

Transformers are self-protected against all faults due to lightning, surges, short circuits, and harmful overloads. Units have lightning arresters and built-in secondary circuit breaker, utilizing current and oil temperature for protection. An emergency control handle permits immediate restoration of service during temporary overloads so that breaker will carry greater overloads for longer periods of time. Protective links in series with the high voltage line leads provide protection against feeder lockouts in the event of short circuits within the transformer.

The ACP transformer is a completely packaged unit, easy and quick to install. A red signal light indicates when the transformer enters maximum safe operating band, and remains lit to provide visual load check. Either expulsion or valve type lightning arresters are provided for high voltage winding protection. A chuck type high voltage bushing terminal for protection against exposed live parts is included in the 2,400-volt class.

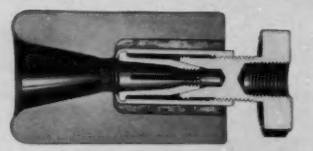
MORE FACTS about new equipment listed here can be obtained by writing the Allis-Chalmers ELECTRICAL REVIEW, Milwaukee 1, Wisconsin.

THESE *ACP** FEATURES MEAN SAVINGS TO YOU!



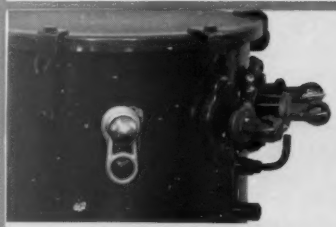
1 LOW VOLTAGE BREAKER, internally mounted, protects against all secondary overloads and short circuits.

2 LIGHTNING ARRESTERS, either expulsion or valve type, assure complete high voltage surge protection.



3 CHUCK TYPE CONNECTORS eliminate all exposed live parts. To make connection, simply insert lead, rotate housing.

4 TANK DISCHARGE GAP provides path for surges on units where ungrounded tank practice is used.



5 LOW VOLTAGE NEUTRAL GAP provides surge protection for LV winding. Can easily be replaced with ground strap.

6 SIGNAL LIGHT, HOOKSTICK RESET and emergency service restoration lever are mounted in one compact assembly.

Simplified Installation . . . Fewer Outages . . . Visual Load Checks Mean Money Saved on ACP Transformers with Premium Protection

ACP TRANSFORMERS PAY THEIR OWN WAY from the moment installation starts. They're economical to install because transformer and protective components are completely packaged in one easy-to-install unit. No assembling or adjusting in the field.

FEWER OUTAGES, INCREASED CAPACITY

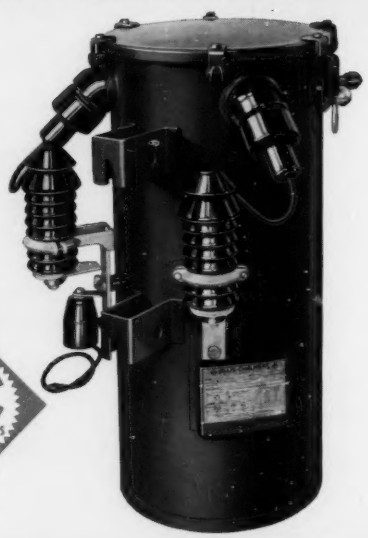
Once they're up, ACP transformers stay on the line longer than conventional units. Secondary breaker, actuated by oil temperature or excess current, is closely coordinated with thermal characteristics of the transformer it protects. Result: short time overload transformer capacity is fully utilized . . . the number of outages reduced.

KEEP TAB ON SYSTEM LOADING

You also eliminate expensive load checks requiring time and special equipment. On ACP transformers 5 kva and up, signal light does the job for you — provides simple, continuous check.

Want more details? NEW ACP transformer bulletin 61B7309A is off the press! Call your nearby A-C district office for your copy. A-3004

Allis-Chalmers, 848-A S. 70th St.
Milwaukee, Wisconsin



*ACP (Allis-Chalmers Protected) is an Allis-Chalmers trademark.

A-C ALLIS-CHALMERS

ALLIS-CHALMERS

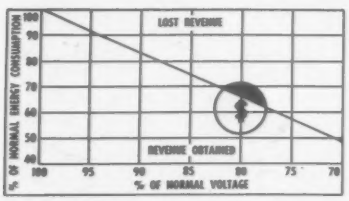
T. H. BLOODWORTH
CONTROL
M. O. ANNEX

Increase Revenue by Correcting Rural Voltage

ALLIS-CHALMERS 5/8% STEP *Pole-Type* VOLTAGE REGULATOR

- Provides full 20% range of regulation in 32—5/8% steps (10% raise and lower)
- Increases line and system capacity — boosts revenue
- Satisfies customers — helps build additional loads
- Costs but a few dollars per customer to install on average line

Look at the Extra Revenue You Get



THE CHART SHOWS the energy consumption for incandescent lamps at varying voltages . . . illustrates the increase in revenue you can get by providing correct voltage at all times.

But boosting voltage is just one part of the job of correcting the rural low voltage problem.

For the first time, a small, economical unit for *regulating* (not just boosting) rural voltage is available.

Allis-Chalmers new pole type voltage regulator is a fully automatic 5/8% step unit . . . has a 20% range of regulation and holds ± 1 volt band. Rating is 10.8 kva, 15 amp, 7200 v, ± 10% regulation. Three years of field tests have proved its reliability.

In addition, easy maintenance — easy mounting — simple control are provided . . . *Contact life is long.* Quick-break mechanism minimizes arcing and pitting. Small 5/8% steps mean contacts interrupt smaller kva — last longer. Unit is mounted on pole as easily as distribution transformer . . . *Control* requires just two simple knob adjustments to set.

Ask an A-C engineer to determine the best means of improving voltage conditions on your rural system using voltage regulators. Contact a nearby A-C district office or send in the coupon.

ALLIS-CHALMERS

Pioneers in Load Ratio Control — Originators of 5/8% Step Regulation

Allis-Chalmers, 848-A S. 70th St.
Milwaukee, Wisconsin

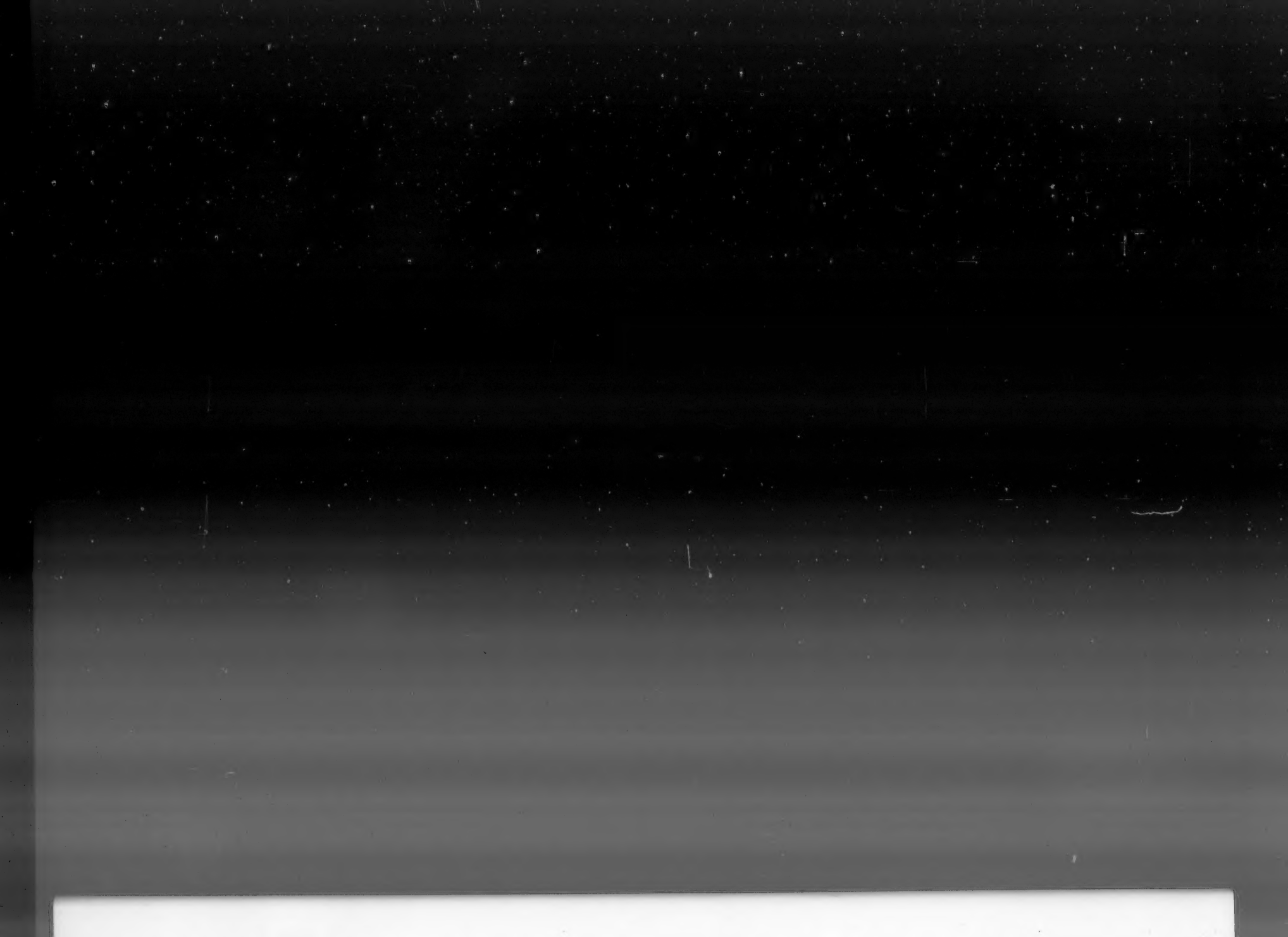
☐ Send me descriptive bulletin 6424, plus "When and Where to Apply Rural Voltage Regulators" bulletin 6409.

Name.....

Title.....

Company.....

Street.....

City.....State.....

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